Threshold of the precedence effect in noise

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Three effects that show a temporal asymmetry in the influence of interaural cues were studied through the addition of masking noise: (1) The *transient precedence effect*—the perceptual dominance of a leading transient over a similar lagging transient; (2) the *ongoing precedence effect*—lead dominance with lead and lag components that extend in time; and (3) the *onset capture effect*—determination by an onset transient of the lateral position of an otherwise ambiguous extended trailing sound. These three effects were evoked with noise-burst stimuli and were compared in the presence of masking noise. Using a diotic noise masker, detection thresholds for stimuli with lead/lag interaural delays of 0/500 μ s were compared to those with 500/0 μ s delays. None of the three effects showed a masking difference between those conditions, suggesting that none of the effects is operative at masked threshold. A task requiring the discrimination between stimuli with 500/0 and 0/500 μ s interaural delays was used to determine the threshold for each effect in noise. The results showed similar thresholds in noise (10–13 dB SL) for the transient and ongoing precedence effects, but a much higher threshold (33 dB SL) for onset capture of an ambiguous trailing sound.

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I. INTRODUCTION

The precedence effect discloses an emphasis of early-arriving cues in the lateralization and localization of sounds (for reviews, see [Blauert, 1983](#); [Zurek, 1987](#); [Litovsky et al., 1999](#)). Such effects are suspected of being responsible for the accurate localization of sound in the presence of reflections and reverberation and for the stable perception of acoustic sources in the presence of fluctuating interaural cues. They are further thought to contribute to the ability of normal-hearing binaural listeners to localize and understand talkers in challenging acoustic environments.

The precedence effect has been most frequently studied with two similar sounds, one trailing the other, as an analog of a direct sound and a single delayed reflection. Strongest dominance of the lead sound is typically found with delays of the lagging sound in the range 1–10 ms. A distinction is often made between the precedence effect observed with brief transient stimuli and that seen with long-duration sounds. Transients, by their nature, include an abrupt stimulus onset, a feature that has been proposed to be responsible for triggering one or more auditory mechanisms that could give rise to the temporal asymmetry that defines the precedence effect [e.g., hair-cell adaptation ([Hartung and Trahiotis, 2001](#)) or central onset-triggered response suppression ([Lindemann, 1986](#); [Zurek, 1987](#); [Xia et al., 2010](#))]. Physiological studies (e.g., [Parham et al., 1996](#); [Fitzpatrick et al., 1999](#); [Tollin et al., 2004](#)) have demonstrated diminished responses to lagging sounds in several auditory

structures that recover on a time course largely consistent with behavioral responses. The term transient precedence effect will be used here to mean the phenomenon observed with brief transient stimuli.

The precedence effect can also be observed with long-duration lead and lag stimuli that do not possess an abrupt onset ([Zurek, 1980](#); [Braasch et al., 2003](#); [Dizon and Colburn, 2006](#); [Freyman et al., 2010](#)). Stimuli composed of lead and lag noise (or noise burst) components that are hundreds of milliseconds or longer also elicit the precedence effect with a dependence on lag delay similar to that seen with transients. In this case, it is not the interaural cues at the onset but those of the ongoing lead component that largely control lateralization. These findings suggest the need to find steady-state lead-dominance mechanisms to supplement those proposed to account for the transient precedence effect (e.g., [Braasch and Blauert, 2003](#); [Braasch, 2013](#)). The precedence effect observed with extended stimuli lacking an abrupt onset has been called the “ongoing precedence effect” ([Freyman et al., 2010](#)).

The third phenomenon showing strong onset dominance is observed when an onset transient determines the localization or lateralization of a long-duration trailing sound. [Freyman et al. \(2010\)](#) described such a case in which a train of brief binaural noise bursts possesses alternating interaural delays. When this noise burst train (with 250-ms duration) is presented with a very slow rise, subjects respond with highly-variable estimates of its lateral position. However, when the train is presented with an abrupt onset, the lateral position of the entire stimulus is consistently matched to that of the interaural delay of the first burst. This phenomenon will be called the “onset capture effect.”

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This onset capture effect observed in lateralization studies is reminiscent of the well-known Franssen effect (Franssen, 1962; Yost *et al.*, 1997; Hartmann and Rakerd, 1989; Dent *et al.*, 2007). In the Franssen effect, an abruptly-gated pure tone is separated into the onset transient part, which is presented from one loudspeaker, and the steady-state tonal part presented from another loudspeaker. Listeners localize the steady tone at the loudspeaker that delivers the transient, not at the one that delivers the trailing steady tone.

There are two important features that are in common between the Franssen effect and the onset capture effect for ambiguous ongoing signals. First, the onset transient controls the perceived location of the ongoing sound only when the ongoing sound is not itself clearly localized/lateralized due to ambiguous or conflicting interaural cues. Franssen (1962) originally observed the effect in a reverberant room, which can distort interaural cues, creating a signal that cannot be localized unambiguously (Hartmann and Rakerd, 1989). In the lateralization measurements of Freyman *et al.* (2010), the implausibility or ambiguity comes from the construction of the stimulus with alternating ongoing interaural time delays (ITDs).

The second common feature is that the spatial perception of the trailing sound, which is captured by the onset transient, lasts a long time. To our knowledge the Franssen effect phenomenon is so long-lasting that the temporal endpoint has not been established. Similarly, onset capture in lateralization for ambiguous ongoing stimuli has been observed to last for at least 5 s and possibly much longer (Freyman *et al.*, 1997).

Important questions remain about the transient and ongoing precedence effects and the onset capture effect—how they facilitate sound localization in challenging listening environments and whether they might be based on common mechanisms. Previous studies have shown that the dominance of a leading sound generally becomes weaker at low sound levels relative to detection threshold. These include studies that used stimuli, such as speech, that comprise a mixture of transient, ongoing, and perhaps onset type features (Leahey and Cherry, 1957; Akeroyd and Guy, 2011) as well as others that used brief bursts of noise (Chiang and Freyman, 1998; Goverts *et al.*, 2000). It is known, therefore, that at least the transient precedence effect and perhaps some combination of transient, ongoing, and onset effects are reduced at levels near detection threshold. To our knowledge, no study has compared the strengths of these three effects near threshold in noise using common methods.

The present study measured the transient precedence effect, the ongoing precedence effect, and the onset capture effect as a function of the common controlling variable of masking noise level. The primary goal was to determine differences among the three effects as a function of masking noise level that might indicate that they are based on different mechanisms. A second purpose was to learn more about the strength of the three effects at low sensation levels in noise in order to understand their role in facilitating stable localizable auditory images in challenging listening conditions.

II. EXPERIMENTAL METHODS

Two types of thresholds were used to compare the behavior of the transient and ongoing precedence effects as well as the onset capture effect. The first takes advantage of the masking level difference (Durlach and Colburn, 1978), or MLD, to determine if any of the three effects is observed at detection threshold in noise. The general MLD result is a lower (better) detection threshold in a test condition in which signal and masking noise have different interaural parameters than in a reference condition in which they have the same interaural parameters. Different parameters of signal and noise give rise to different lateral positions of perceived intracranial images when they are heard separately, while the same interaural parameters lead to the same lateral positions. Stimuli leading to any of the three effects can be tested for an MLD. If diotic noise is used as a masker, then a precedence or onset capture stimulus with a non-zero leading interaural delay might be easier to detect than one with a zero leading delay. This can be stated more succinctly if we let $T/0$ denote a lead interaural delay of T and a lag interaural delay of 0 (and similarly, let $0/T$ denote lead and lag interaural delays of 0 and T , respectively). Then: (1) If either type of precedence effect or the onset capture effect operates near masked threshold, and (2) if a $T/0$ stimulus is lateralized according to the dominant lead delay of T while the $0/T$ stimulus is lateralized near midline, then detection threshold in diotic noise should be lower for the $T/0$ than for the $0/T$ stimulus.

The second type of comparison among the three effects was done in terms of discrimination. If any of the three effects (transient, ongoing, or onset capture) is fully operative, then it should be easy for a listener to discriminate a $0/T$ from a $T/0$ stimulus (provided T is sufficiently different from 0). This comparison examines performance discriminating $0/T$ from $T/0$ as a function of noise level. The signal-to-noise ratio (SNR) at which this discrimination can be performed to a criterion level is considered the threshold for the effect in noise.

In total, with the inclusion of two additional reference detection conditions, performance was measured in four detection tasks and one discrimination task using stimuli for each of the three effects (transient precedence effect, ongoing precedence effect, and onset capture effect). These detection and discrimination tasks will be described in conjunction with the description of the stimuli below.

A. Stimuli

Stimuli were generated on a personal computer at a 20-kHz sampling rate with a 24-bit sound card (Creative Sound Blaster), low-pass filtered at 8.5 kHz, attenuated [Tucker-Davis Technologies (TDT PA4)], and delivered through TDH-39 headphones (Telephonics) via a headphone amplifier (TDT HB5) and a passive attenuator. The level of the masker remained constant at 75 dBA as measured in a 6-cc coupler, while signal level was controlled by digital scaling.

1. Transient stimuli

Figure 1(A) shows a schematic diagram of the four basic transient stimuli. Each rectangle on the time line represents a

FIG. 1. (A) Transient stimuli are illustrated schematically in all four stimulus configurations: 0/0, 500/500, 0/500, and 500/0. Each rectangle represents a 1-ms burst of white noise. The letter within the rectangle indicates the identity of the noise token. (B) The first few milliseconds of the ongoing stimuli are illustrated schematically for the 0/500 and 500/0 conditions (two of the four stimulus configurations). In these stimuli the noise burst trains were constructed using a fresh token of noise indicated by different letters in each quad (binaural noise burst pair). The time from the start of one quad to the next was 4 ms. The total stimulus duration was 250 ms. The two conditions not shown are 0/0 (simple diotic) and 500/500 (a simple interaural delay of 500 μ s)—see (A) where all four stimulus configurations are shown for the transient stimuli. (C) The first few milliseconds of the onset capture stimuli are illustrated schematically for the 0/500 and 500/0 conditions, again, two of the four total stimulus configurations. The temporal relations within this stimulus were the same as those of the ongoing precedence effect stimuli—see (B). The difference is that a single noise token was used for the entire train of bursts. The two conditions not shown are 0/0 (simple diotic) and 500/500 (a simple interaural delay of 500 μ s)—see (A) where all four stimulus configurations are shown for the transient stimuli.

1-ms rectangularly-gated burst of white noise. The letter inside a rectangle denotes a particular noise burst token; tokens with the same letter are identical except for a time shift. Tokens with different letters are statistically independent samples of the same Gaussian noise process. Transient stimuli used one token per stimulus, with a fresh token selected on each trial. There were four stimulus configurations.

- (1) A 0/0 stimulus had a diotic noise burst followed 2 ms later by a second diotic noise burst.

- (2) A 500/500 stimulus had a fixed ITD of 500 μ s (left leading) between noise bursts with a lag delay of 2 ms.
- (3) A 0/500 stimulus had a diotic burst leading a dichotic burst with an ITD of 500 μ s. The time from the start of the lead to the start of the lag was 2 ms.
- (4) A 500/0 stimulus had a dichotic burst (with ITD = 500 μ s) followed 2 ms later by a diotic burst.

Each of these stimuli was used as the signal in a four-interval detection task. The masking noise in each interval was a 500-ms burst (with a fresh burst used in each interval). The target signal of one of the four binaural configurations (0/0, 500/500, 0/500, 500/0) was added in the temporal center of the diotic masker in one of the four intervals. This was also the case for the ongoing and onset detection stimuli described below.

In the discrimination task the listener was asked to identify the 500/0 stimulus presented randomly in one of the four intervals among 0/500 alternatives presented in the other three intervals. The stimuli were added to 500-ms diotic noise bursts in each interval at the temporal center of each masker burst. Different masker noise tokens were used in each interval. The signal burst tokens were the same across the four intervals of a trial, but they were different across trials. This was also the case for the ongoing and onset discrimination stimuli described below.

2. Ongoing stimuli

Figure 1(B) shows schematically the ongoing stimuli. These stimuli can be seen to be constructed by appending transient stimuli, with new tokens (indicated by different token letters) selected for each set (called a “quad”). The time from the start of one quad to the next was 4 ms. In a 0/500 stimulus the leading burst in each quad was diotic and the lagging burst had an ITD of 500 μ s. With a 500/0 stimulus the order of interaural delays was reversed. The 0/0 and 500/500 versions of ongoing stimuli are not shown in the figure because they are easily visualized—simply diotic in the 0/0 case and a simple interaural delay of 500 μ s in the 500/500 case. These noise-burst trains contained 126 binaural pairs, resulting in signal duration of 250 ms. Freyman *et al.* (2010) demonstrated that the ongoing precedence effect with this stimulus arises from the lead within each quad, and is not affected appreciably by the ITD at onset. The same detection and discrimination conditions in noise maskers as described for transient stimuli were tested with these stimuli.

3. Onset stimuli

The onset stimuli are shown schematically in Fig. 1(C). The temporal relations within this stimulus were the same as those of the ongoing stimuli. The difference is that a single noise token was used for the entire train of bursts. It should be noted that the only difference between the 0/500 and 500/0 stimuli is the ITD of the first noise burst in the train and that this stimulus is perceived as a single auditory image lateralized in accordance with the ITD of the first burst (Balakrishnan and Freyman, 2002; Freyman *et al.*, 2010).

The same detection and discrimination conditions in noise maskers as described for transient and ongoing stimuli were tested with these stimuli.

B. Subjects

Four normal-hearing listeners (all females) with audiometric thresholds ≤ 20 dB HL at octave frequencies between 500 and 8000 Hz participated in this experiment. Their ages ranged between 21 and 24 yrs. Subjects were undergraduate and graduate students in the Department of Communication Disorders at the University of Massachusetts, Amherst.

C. Procedures

Test sessions were conducted in a double-walled sound-treated booth (IAC 1604). Custom MATLAB software, executed on a desktop computer inside the test booth, was used to present the signals to the subject, provide correct-answer feedback on every trial, and record the subjects' responses. All measurements were made using a four-alternative-forced-choice procedure. Experimental runs consisted of 25 total trials with the first 5 treated as practice and not counted. Psychometric functions were obtained for all detection and discrimination conditions tested. The SNRs selected to obtain these functions were different for each condition and were based on the results of preliminary testing. This exploration of the appropriate SNRs usually began with more favorable SNRs and descended to chance performance. Based on the results of one or two such sets of blocks, four to five SNRs to be used in the actual testing were chosen to cover the range between chance and perfect performance as well as possible. The bulk of pilot testing was conducted by Subject 1; other subjects used these results as a guide, with adjustments to the SNR range made as necessary. SNRs were fixed within a run and ascended in order of difficulty across 5 runs, which were repeated 3 times for a total of 60 trials per data point. A block consisted of a series of four runs in which each of the four interaural conditions (0/0, 500/500, 0/500, 500/0) were tested once, in a random order. These sets were completed for an individual stimulus type (e.g., transient) before beginning another type (e.g., ongoing).

III. RESULTS

Figure 2 displays the psychometric functions for all four subjects for each of the three stimulus types—transient, ongoing, and onset. (Note that data with transient stimuli could not be obtained with Subject 2.) Within each panel, results from the detection and discrimination tasks are shown. The mean percent correct score, which is based on 60 trials, is plotted (with symbols) as a function of SNR in dB. The lines are logistic functions fit to each set of data. This function has the form:

$$p = a + \frac{100 - a}{1 + e^{[(\text{SNR} - m)/s]}}$$

where p is percent correct, $a = 25$, and m and s are fitted parameters.

Psychometric functions increased monotonically with increasing SNR, with 500/500 (simple dichotic) detection performance best and 0/0 (diotic) worst. Detection of the 0/500 and 500/0 signals was similar across tested SNRs, and fell in between the 0/0 and 500/500 conditions, while functions for discrimination were shifted to the right by varying amounts depending on the stimulus type. The slopes of the psychometric functions appear to be consistently shallower for the onset stimuli than for the other two stimulus types in both detection and discrimination, and this was confirmed by comparing the slopes taken from the fitted functions.

The psychometric functions in Fig. 2 were summarized by a threshold, which was defined as the SNR producing 62.5% correct on the fitted function, the midpoint between chance and perfect performance. Thresholds for all conditions and subjects are plotted in Fig. 3. The patterns in the detection results are fairly clear and, to the extent that comparisons are possible, are consistent with past signal detection results. For each stimulus type, detection thresholds are highest for the 0/0 condition, lowest for 500/500, and intermediate for the 0/500 and 500/0 conditions. Further, for each stimulus condition, detection thresholds are highest for transient, lowest for onset, and intermediate for the ongoing stimulus type.

FIG. 2. Psychometric functions for each subject for each of the three stimulus types (transient, ongoing, and onset). Within each panel, results from the detection (500/500 = open circles, 500/0 = open triangles, 0/500 = filled triangles, 0/0 = filled diamonds) and discrimination (filled circles) tasks are shown. The mean percent correct score, which is based on 60 trials, is plotted as a function of SNR in dB. The lines are logistic functions fit to each set of data.

FIG. 3. Thresholds (SNR at the 62.5% correct point) for each of the three stimulus types (transient, ongoing, and onset) and detection and discrimination tasks. Different symbols show the results separately for the four subjects.

The pattern of thresholds across stimulus type is understandable in terms of differences in stimulus duration and power spectrum. Transient thresholds are likely higher because brief signals are generally less detectable (in terms of signal-to-masker power ratio) than longer-duration signals (e.g., Green, 1960). Further, the spectral distribution of stimulus power might account for the difference between ongoing and onset thresholds. Because onset stimuli are made with a repeated single token, while the ongoing stimuli are made with fresh tokens on every other burst, the onset capture stimuli have their power concentrated at harmonic frequencies while the ongoing stimuli have a more evenly distributed noise-like spectral shape. Concentration of signal power at a few frequencies would increase the SNR within some auditory filters, leading to better signal detectability.

The difference between the detection thresholds in the 0/0 and 500/500 conditions defines a simple MLD for the three stimulus types. With transients this MLD was 5.2 dB, while for ongoing and onset capture stimulus types it was 13 and 10.5 dB, respectively. A one-way analysis of variance revealed a main effect of stimulus type on the size of the MLD [$F(2,1) = 33.06$, $p = 0.007$]. Follow-up t -tests revealed that the onset and transient MLDs were different [$t(2) = 7.086$, $p = 0.019$], as were the transient and ongoing effects [$t(2) = -7.600$, $p = 0.017$]. The relatively small MLD with transient stimuli is consistent with MLDs for similar conditions reported by Yost and Soderquist (1984). The increase in the MLD with burst-train duration is consistent

with the findings of Dye and Yost (1986), who used broadband pulse trains with varying number of pulses.

The question of an MLD for transient, ongoing, and onset stimuli is answered in Fig. 3 by the finding that, for all three stimulus types, thresholds for 0/500 and 500/0 detection conditions are essentially identical. The differences between these two conditions were 0.32, 0.03, and 0.25 dB for the transient, ongoing, and onset effects, respectively. None of these differences was statistically significant. There is a clear threshold improvement going from the diotic 0/0 condition to either 0/500 or 500/0, indicating that there was some basis for binaural unmasking for those dichotic signals. However, the equivalence of the amount of unmasking for 0/500 and 500/0 indicates no detection advantage for a signal that, in quiet, is strongly lateralized (500/0) relative to one (0/500) that has the same lateral position as the diotic noise masker. It is clear that, at least for the stimuli used here, there is no indication of a precedence- or onset capture-based MLD.

The robustness of either of the precedence effects or the onset-capture effect in noise is measured by the ability to discriminate between 0/500 and 500/0 stimuli. In order to make this comparison it is necessary to normalize the discrimination threshold to the relevant detection threshold, which is the average of the (nearly-equal) 0/500 and 500/0 thresholds, for each stimulus type. These normalized thresholds are plotted in Fig. 4. Transient stimuli must be about 10 dB above threshold and ongoing stimuli about 13 dB in order for listeners to discriminate 0/500 stimuli from 500/0 stimuli. Onset stimuli, in contrast, must be 33 dB above detection threshold, on average, for threshold discrimination performance.

IV. DISCUSSION

The current study was conducted to investigate similarities and differences among the transient precedence effect, the ongoing precedence effect, and the onset capture effect. Background noise was varied systematically to determine if these effects are observed at masked threshold, and to determine their robustness in noise. Results indicated that none of the three effects was operative at masked threshold. In terms of robustness, however, there was a clear distinction. Performance on a discrimination task showed thresholds for the transient and ongoing precedence effects 10 to 13 dB above detection thresholds for the test stimuli. Thresholds

FIG. 4. Normalized discrimination thresholds are plotted for the transient, ongoing, and onset stimuli. Discrimination thresholds have been normalized to the average of the 0/500 and 500/0 detection thresholds, for each stimulus type.

for the onset capture effect, on the other hand, were 33 dB above detection threshold.

The effects of noise on the precedence effect observed in this study can be compared to previous results from normal-hearing listeners. [Leakey and Cherry \(1957\)](#) studied the effect of background noise on the precedence effect for speech stimuli in free-field conditions using a time-intensity trading paradigm. For a 2.2-ms lag-delay, similar to the 2-ms delay used in the present study, [Leakey and Cherry \(1957\)](#) observed that the level of the lagging sound needed to be increased by only approximately 2 dB relative to the lead in order to offset the precedence effect when the signals were presented in noise at 10 dB SL. This is in contrast to the 10 dB increase in lag level required to counteract the precedence effect at high SLs. Thus, the introduction of background noise with speech signals at 10 dB SL produced a substantial reduction in the strength of the precedence effect relative to quiet conditions.

Using wideband noise bursts of 4-ms duration with a 2-ms lag delay, [Chiang and Freyman \(1998\)](#) replicated the findings of [Leakey and Cherry \(1957\)](#) using time-intensity trading, but in a direct localization task found that the precedence effect was quite strong at SLs as low as 10 dB when lead and lag sounds were at equal levels. Across subjects, the value of lead weighting, or c ([Shinn-Cunningham et al., 1993](#)) averaged above 0.9 even at 10 dB SL in noise. [Chiang and Freyman \(1998\)](#) concluded that the precedence effect was not as weak at low SLs as had been thought from time-intensity trading results, and suggested that the potency of the relative intensity metric itself may be dependent on noise level, perhaps through the same mechanisms that produce rapid loudness growth in noise. A possible explanation for the difference between the strong precedence effect at low SLs seen by [Chiang and Freyman \(1998\)](#) with sound field listening, and the weak effect measured here with headphone listening, is that both interaural delay and level difference cues were available in the sound field, while only delay cues were presented in our headphone study, with level differences fixed at 0. This difference suggests that caution should be exercised in extrapolating from headphone to free field results on the strength of the precedence effect.

[Goverts et al. \(2000\)](#) investigated the precedence effect at low sensation levels, both in quiet and in noise, using 5-ms noise signals (for lead and lag combined) presented under headphones. They found that mean left/right laterality judgments consistent with the direction of the lead increased from 50% (no precedence effect) near detection threshold to 90% or more above 30 dB SL. This trend showing a weakening of the precedence effect at low SLs is consistent with the current results.

The relationship between the precedence effect and binaural detection has also been studied previously, with somewhat inconsistent results. [Yost and Soderquist \(1984\)](#) were the first to investigate whether the precedence effect influenced binaural detection. In the presence of diotic noise, they found that pairs of brief binaural pulses were better detected when the lead pulse was dichotic than when it was diotic. That is, there was more release from masking, relative to a 0/0 condition, when the lead was dichotic. [Balakrishnan and Freyman \(2002\)](#) studied the detection of trains of

identical bursts with alternating ITDs, similar to the onset capture stimuli used in the current study. They observed no difference in detection between conditions in which the leading ITD either did or did not match the ITD of the masking noise. This finding was also observed for transient stimuli in a follow-up experiment. The current study supports these findings and extends them to the case where noise tokens change after each pair of binaural noise bursts (quads) and lateralization is based on the leading bursts in each quad in an ongoing signal. The data presented here suggest that neither type of precedence effect nor the onset capture effect helps listeners detect weak signals in noise.

For stimuli with simple consistent interaural delays, a difference in the lateral positions of target and masker is predictive of release from masking ([Haft et al., 1969](#)). However, this relationship between lateralization in quiet and release from masking in noise apparently does not hold for stimuli used here that are lateralized based on the transient or ongoing precedence effects or the onset capture effect. The equivalence of detection thresholds for 0/500 and 500/0 stimuli, and the fact that those stimuli are not discriminable until they are 10 dB or more above detection threshold, indicates that neither of the precedence effects, transient or ongoing, nor the onset capture effect, is operative for signals near masked threshold.

The high sensation level required to reach discrimination threshold for the onset capture effect reveals its fragility relative to the transient and ongoing precedence effects. This may be understandable, considering that the ongoing part of the onset capture stimulus (when gradually gated) has an ambiguous lateral position ([Freyman et al., 2010](#)) and that the effect requires that the entire signal is lateralized according to the ITD of the very first burst pair out of a total of 126 pairs that are alternating in ITD. From this point of view it is plausible that this initial burst pair has to be well above threshold in order to exert lateral control.

The stimuli used to evoke the onset capture effect in this study were constructed with ongoing parts that were spatially ambiguous. But onset dominance in lateralization can also be observed for signals that are easily localized when presented without an abrupt onset ([Kunov and Abel, 1981](#); [Abel and Kunov, 1983](#); [Saberi and Perrott, 1995](#); [Freyman et al., 1997, 2010](#)). [Haft et al. \(1983\)](#) and [Haft and Buell \(1990\)](#) found that later clicks in a click train with short interclick intervals contribute less to ITD discrimination than the initial clicks in the train. Stimuli with randomly perturbed ITD's across a train of clicks are lateralized with a temporal weighting function that most heavily favors the ITD of the first click in the train (e.g., [Brown and Stecker, 2010, 2011](#); [Stecker et al., 2013](#)).

There appear to be at least three important distinctions between the onset capture of a trailing sound that is spatially ambiguous and the onset dominance of a sound that is spatially unambiguous. The first is that onset dominance for unambiguous ongoing stimuli is highly dependent on the steady ongoing ITD. For example, the effect is not very strong when the ongoing stimulus is diotic ([Freyman et al., 2010](#)). A second distinction is that the lateralization of ambiguous ongoing sounds can be captured by relatively weak

onset cues (e.g., a simple gating delay), whereas an unambiguous sound is not easily captured by this type of onset cue (Buell *et al.*, 1991; see also Zurek, 1993). The third difference is that when the ongoing delay is unambiguous, several listeners reported that control of lateralization by the onset disappeared by 5 s duration for stimuli in which strong onset dominance was observed for durations of 250 ms (Freyman *et al.*, 1997). In contrast, presentation of a transient onset followed by ambiguous ongoing signals for 5 s did not, in informal observations, appear to elicit any degradation in the effect (Freyman *et al.*, 1997); similar long-lasting onset capture characterizes the Franssen effect.

Although onset dominance for spatially unambiguous ongoing sounds is, in our view, interesting from a theoretical standpoint, its potential to simulate real world phenomena may be limited. The unambiguous stimulus condition does not simulate a sound source plus single reflection because a single transient sound would not produce a sustained reflection from one location. In almost all situations multiple reflected signals combine to create a jumble of interaural cues. A spatially ambiguous ongoing sound following a transient may be a more realistic simulation.

As is often the case, generalizing laboratory results obtained with simple stimuli to real-world scenarios is difficult. Signals of interest are not simple repetitive bursts, interfering noise is not always steady, and acoustic conditions give rise to many more than one reflection of a direct sound. Speech contains a mixture of plosive and continuant sounds, both aperiodic and periodic, that could evoke either transient or ongoing effects, including the onset-capture effect. Based on the high sensation level required for the onset capture effect seen in the present data, one might expect little real-world role for it in background noise. However, it must be remembered that the onset burst in the present onset capture stimuli had the same structure and power as each of many trailing bursts. In real-world conditions a transient onset often has greater power than the trailing reflections. Combined with fluctuations in real background noise, it is plausible that the onset capture effect plays a greater role in real noisy environments than is suggested by the present data.

In summary, the results of this study of precedence and onset capture effects in noise show in two ways that none of those effects plays a role with signals that are at or close to detection threshold. First, although expected MLDs (re: diotic) were measured for such stimuli, there was no differential effect of making the lead sound diotic or dichotic. Second, sensation levels needed for the effects to be detectable were 10 to 15 dB for the transient and ongoing precedence effects, and 30 to 35 dB for the onset capture effect. The greater fragility of the onset capture effect in noise suggests that the mechanisms responsible for it may be different from those responsible for precedence effects.

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