How Masking affects Auditory Objects of Beamformed Sounds

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Introduction

The controllable directivity of loudspeaker arrays allows the "orchestration" of reflecting surfaces in a room, resulting in one option of auditory object positioning [1]. Also in distance, the level of diffuse reverberation is influenced by the directed sound beams. As one example the icosahedral loudspeaker array (IKO, cf. Figure 1) uses these effects of spatialization in electroacoustic music. Earlier studies [2, 3] reveal that for stationary signals the beam directivity and its orientation is largely determining the localization. By contrast, for transient signals the precedence effect is much stronger, and despite beamforming to specifically excite wall reflections, frequently the direct path determines localization. Current electroacoustic composition elements for the IKO (Miniatur 20 [4]) specifically utilize masking signals to suppress this increased precedence effect for transient sounds, to support locations deviating from the direct path.
This contribution investigates how different maskers influence the perception of transient sounds. We briefly discuss the precedence effect and our motivation of this study. Subsequently, a listening experiment is sketched to study the influence of two different maskers on the perception of transient sound. In the last section the experimental results are discussed.

Precedence Effect

The precedence effect or law of the first wavefront implies that the perceived location of a sound source is determined by the first arriving sound at a listening position. Several studies could show that precedence is stronger for transient signals than for signals with no transient character, cf. [5]. In line with this, listening experiments with the IKO in the field of spatial computer music reveal a difficulty in the detachment from the physical location of the IKO with transient sounds [6]. During his work on spatial sound phenomena created by the IKOs reflections, the composer Gerriet K. Sharma noticed that by adding a broadband masker transient, auditory objects appeared to be more lateralized and more distant from the IKO. An explanation of this effect is found studies on the precedence effect: listening experiments revealed a substantial weakening effect of background noise on the precedence effect, cf. [7].

Experimental Setup

This experiment investigates the influence of masking noise on the perception of transient auditory objects created by the IKO.

Figure 1: The icosahedral loudspeaker array (IKO)

Two masker types are studied: the *pink masker* represents broadband pink noise played back with omnidirectional directivity by the IKO and the *room masker* represents the noise floor of the listening room present in quite. The *transient sound* is a sequence of regular bursts played back with 3rd-order directivity pattern directed to the angle φ. It is obtained by a combination of Legendre-Polynomials $P_n(\cos\vartheta)$

$$g_i(\vartheta) = \frac{\sum_{n=0}^{i}(2n+1)\,P_n(\cos\frac{137.9^\circ}{i+1.51})P_n(\cos\vartheta)}{\sqrt{\sum_{n=0}^{i}(2n+1)\,[P_n(\cos\frac{137.9^\circ}{i+1.51})]^2}} \qquad (1)$$

using the so-called max-$\boldsymbol{r}_\mathrm{E}$ weights, cf. [8, 9] and yields a relatively narrow main lobe and sufficiently suppressed side lobes. The resulting 3rd-order directivity pattern is shown in Figure 2.

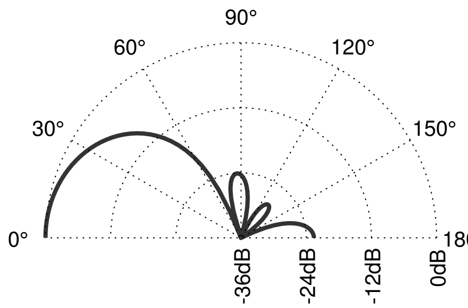


Figure 2: Beampattern design: 3rd-order max-$\boldsymbol{r}_\mathrm{E}$ directivity pattern

The experimental setup is derived from a basic staging constellation of the IKO in electroacoustic music [6] in the IEM CUBE ($10\,\mathrm{m} \times 11\,\mathrm{m} \times 4\,\mathrm{m}$ with $T_{60} = 0.7\,\mathrm{s}$).

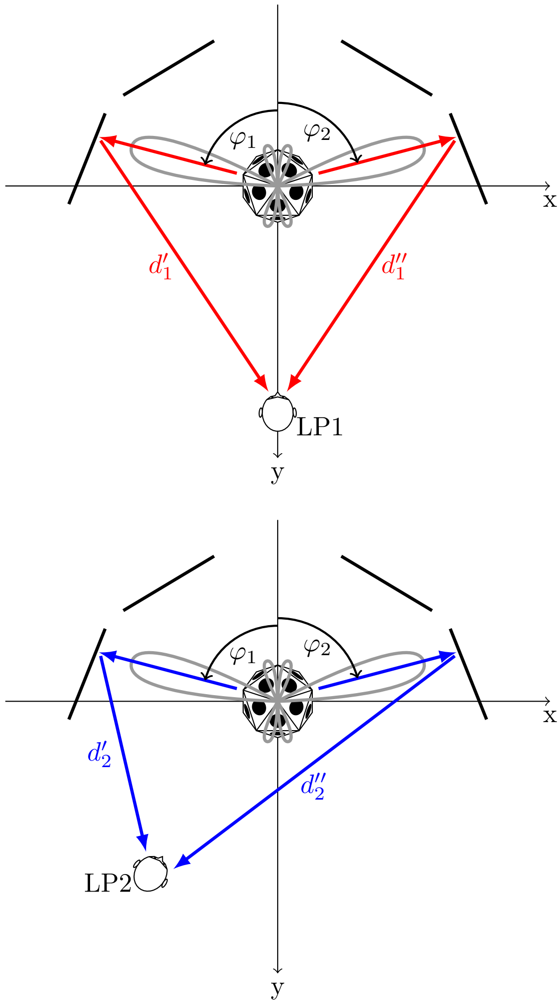


Figure 3: Diagram for the listening experiment. The listening position 1 (LP1) was directly in front of the IKO with a distance of 2.5 m. Listening position 2 (LP2) was further ahead and approximately 1 meter apart. The reflectors were placed symmetrically around the IKO. Symbolical direct paths for the left and right sound beams for each listening position are shown in red (LP1) and blue (LP2). The 3^{rd}-order beampattern for each direction and the two direction-angles φ_1 and φ_2 are also depicted symbolically.

Table 1: Composition of stimuli used in the listening experiment with corresponding sound pressure levels of the transient sound and the masker measured at LP1. All conditions were tested twice with different beam directions of the transient sound ($\varphi_1 = -59°, \varphi_2 = 57°$), except for the reference condition ($\varphi = 180°$).

cond.	trans. signal lvl.	masker type	masker lvl.
R	65 dB(A)	(room)	25 dB(A)
P0	65 dB(A)	(room)	25 dB(A)
P1	65 dB(A)	pink	59 dB(A)
P2	65 dB(A)	pink	65 dB(A)
Q1	29 dB(A)	room	25 dB(A)
Q2	32 dB(A)	room	25 dB(A)

Two reflectors pairs were arranged on a semicircle of $r = 2.3$ m behind the IKO with listening positions LP1 and LP2 on the opposing side, cf. Figure 3.

The composition of tested conditions is listed in Table 1. Pink masker conditions (P0, P1, P2) were tested at three different masking levels while keeping constant the level of the transient sound. Room masker conditions (Q1, Q2) were tested with two different levels of the transient sound close to the room noise in quite. Obviously, the room masker was always present. All conditions were tested with the transient sound steered to the left ($\varphi_1 = -59°$) and to the right ($\varphi_2 = 57°$) reflector pair. The test set is completed by a reference condition (R) consisting of a the transient sound steered towards LP1 ($\varphi = 180°$). This leads to 2 (left/right) x 5 (P0, P1, P2, Q1, Q2) + 1 (R) = 11 different conditions for each set tested at LP1 and LP2, cf. Figure 3.

The listeners' task was to estimate the lateralization of the transient auditory object on a graphical user interface displaying a continuous slider for each condition in a multi-stimulus set including all 11 conditions. The leftmost position of the sliders represented the lateralization on the leftmost reflector and the rightmost position on the rightmost reflector.

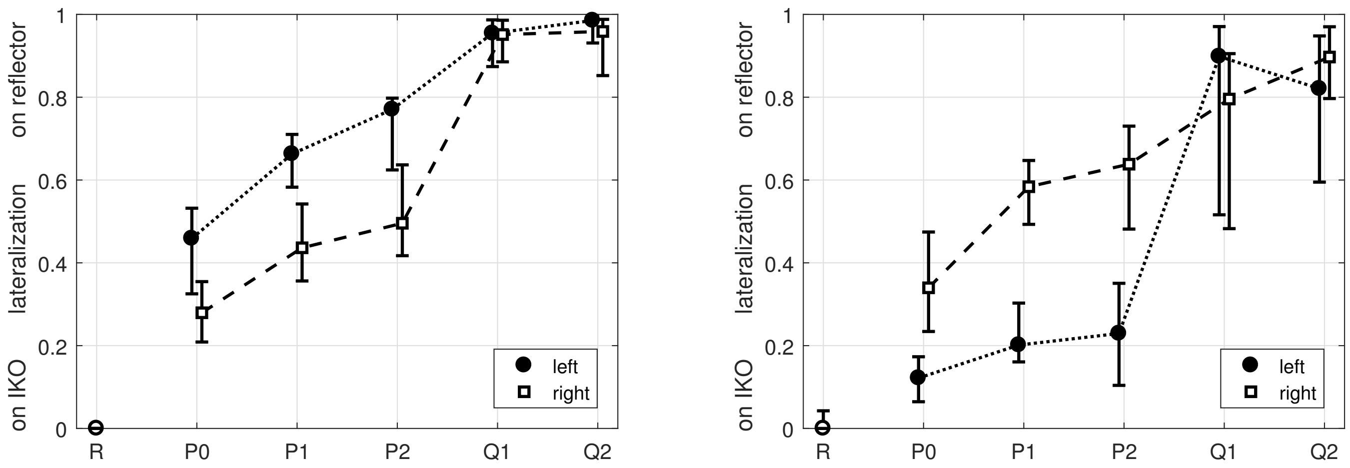
The 11 conditions were tested twice for both listening positions in random order. Eleven experienced and normal hearing listeners participated in the test that lasted 20 minutes on average.

Experimental Results

Results for left/right conditions are mirrored accordingly and Figure 4 shows median values and corresponding 95% confidence intervals of each condition and both listening positions. For both listening positions, the reference condition R was always heard at the position of the IKO.

At LP1 the lateralization of the transient auditory object increases with increasing level of the pink masker (P0, P1, P2) and it is perceived to be most lateralized with room masker conditions (Q1, Q2). A pairwise analysis of variance (ANOVA) reveals room masking conditions Q1 and Q2 not to be significantly different for both directions left and right ($p \geq 0.43$). The same holds for pink masking conditions P1 and P2. In contrast, there is a significant difference between P0 and P1/P2 ($p \ll 0.01$), as well as between the pink noise conditions P0/P1/P2 and room noise conditions Q1/Q2 ($p \ll 0.01$). This results in 4 groups of significantly different lateralizations: {R},{P0},{P1,P2},{Q1,Q2}.

Interestingly, the comparison of the left and right results at LP1 reveals significant differences of all pink masking conditions, whereas there is no significance found for left and right room masker conditions. An explanation thereof could be the positioning of the reflectors. Listeners reported to hear left conditions to be louder than right conditions.



(a) Listening position LP1 (b) Listening position LP2

Figure 4: Results of both listening positions depicted as mean values and 95% confidence intervals. Filled maskers represent left conditions ($\varphi_1 = -59°$) and empty maskers right conditions ($\varphi_2 = 57°$).

At LP2 similar relations are found for both left/right conditions: There is no significance between P1 and P2 and no significance between Q1 and Q2. The lateralization of right conditions resemble corresponding conditions in LP1, whereas for left conditions the influence of pink masker level is no longer pronounced and auditory objects are perceived in the vicinity of the IKO. Room masker conditions on the other hand remain at the reflector. If we compare the sizes for 95% confidence intervals we see high variance of room masker conditions for LP2. An explanation could be the level decrease of respective transient signals due to an increase of the sound propagation path (right condition) or deterioration of the reflection caused by the reflector angle (left), which makes localization tasks more difficult.

Conclusion

This contribution investigated the influence of maskers on the perception of transient auditory objects created by reflected sound beams. We could show that omnidirectional pink masking noise weakens the precedence effect and increases the lateralization of the transient sounds. The effect was shown to be robust for different masking levels (P1 vs. P2), however influenced by the listening position and reflector positioning. A stronger effect is achieved for softer transient sounds close to the level of the room noise: Lateralization of respective conditions was highest for both listening positions with the drawback that the transient sounds were sometimes barely audible.

Acknowledgments

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