Environmental Influence on the Fine Structure of Dummy-Head HRTFs

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The directional filtering of the outer ears is a significant step during the evaluation of spatial information. A computer-controlled dummy-head measurement system was developed to measure the HRTFs in huge amount and with increased spatial resolution. Effects and common properties of objects near the head (glasses, hair, baseball cap) were measured. Changes in the HRTFs due to the acoustical environment will be presented as function of frequency and azimuth for different elevations on 2D polar diagrams. Differences of about 1 dB are evaluated in the fine structure of the measured HRTFs and conclusions are drawn for the relevance of HRTF reproduction in binaural synthesis.

1 Introduction

The acoustical environment near the head influences the Head-Related Transfer Functions significantly [1-3]. Using a precisely controlled measurement system we measured the HRTFs of a dummy-head in different acoustic environments. With the help of the simple mathematical tool of the Head-Related Transfer Functions Differences (HRTFD), differences related to objects near the head - such as baseball caps, glasses and hair - are presented on 2D polar diagrams as function of frequency and azimuth [4-6].

2 HRTFD

2.1 Definitions

The Head-Related Transfer Function Differences were defined as the quotient of HRTFs from the same direction under modified environmental conditions [6, 7]:

$$HRTFD = \frac{HRTF_{C2}}{HRTF_{C1}} \qquad (1)$$

where C_1 identifies the reference and C_2 the modified condition. We plot the 20log/HRTFD/ magnitude response as the function of frequency or as 2D polar histogram as function of frequency and azimuth.

Now, the reference condition is the "bare" torso and C_2 will be the torso having glasses or hair or a baseball cap. Of course, the HRTFDs in these cases will not only show the effect of these objects but also the natural deviations and uncertainities of the "bare" torso as shown in [5, 7]. Nevertheless, this kind of polar representation is well suited to investigate common effects of these objects and as well as the variation of the head-shadow area.

2.2 Goals

The goal is to show, how much these commonly used, everyday objects influence the fine structure of the HRTFs. It is well known that virtual audio synthesis through headphones may suffer from decreased localization performance and it is suggested to have individual and more "accurate" HRTFs during the simulation for a better localization. The use of non-individual or dummy-head HRTFs can lead to localization errors [8-13].

On the other hand – as our results also show – small modifications in the acoustic environment near the head could provide large variations in the HRTFs. If we put on a hat or a cap, if we are wearing our sunglasses or just simply let our hair cut…the HRTFs change. But we never met anybody who reported decreased localization performance or significant change in the spatial sensation due to these…

We like to show that the filtering of the HRTFs is a basic pre-filtering tool for the decoding of the acoustical information, but they can be too variable due to small changes in the acoustical environment near the head. Hence, in virtual audio synthesis other localization cues – such as head movements, room reverberation and cancelling of headphone errors – are more important.

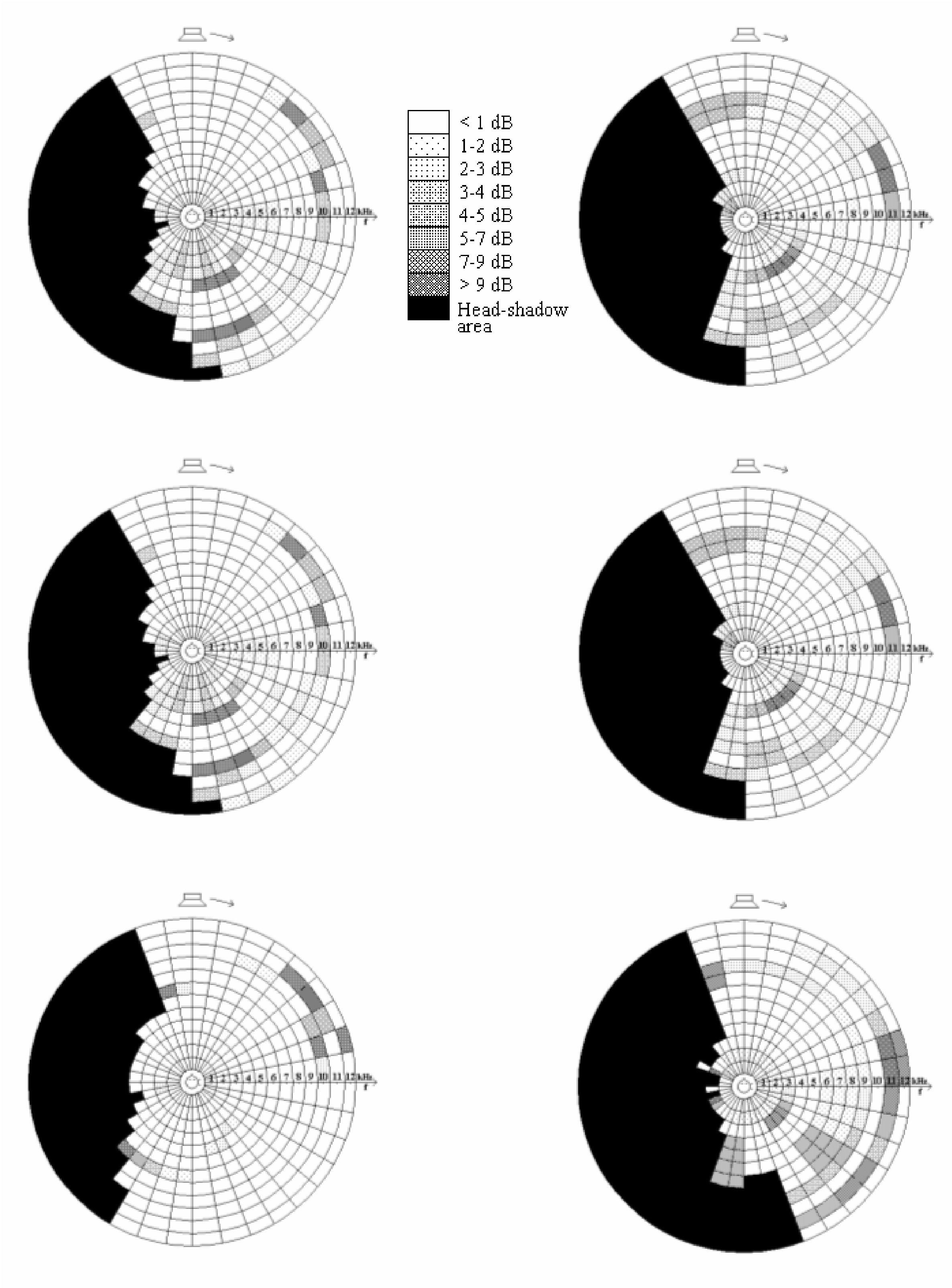

Figure 1: HRTFDs showing the effect of hair (above), baseball cap (middle) and glasses (below) from the elevation –10° (left column) and 0° (right column)

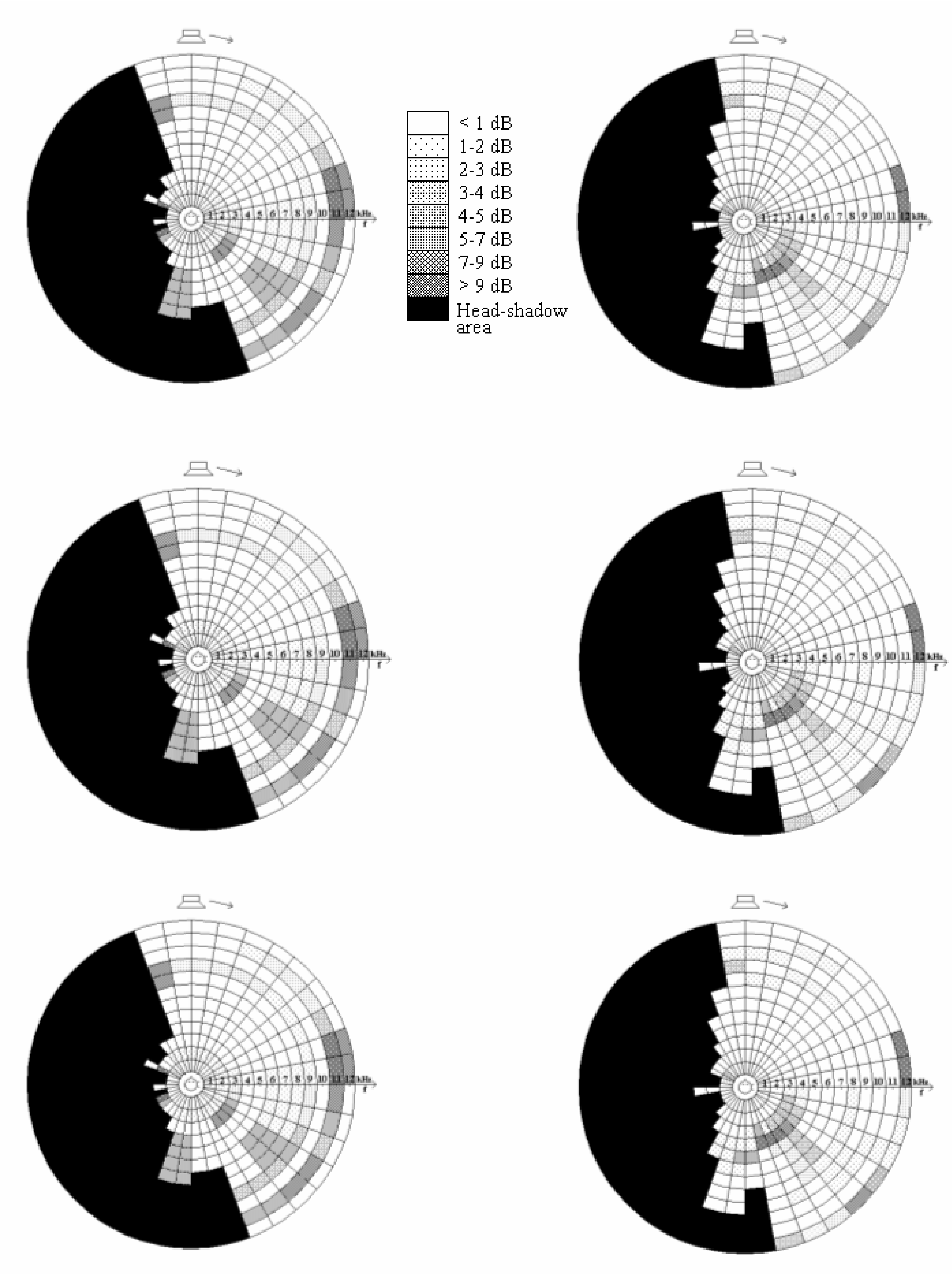

Figure 2: HRTFDs showing the effect of hair (above), baseball cap (middle) and glasses (below) from the elevation +10° (left column) and +20° (right column)

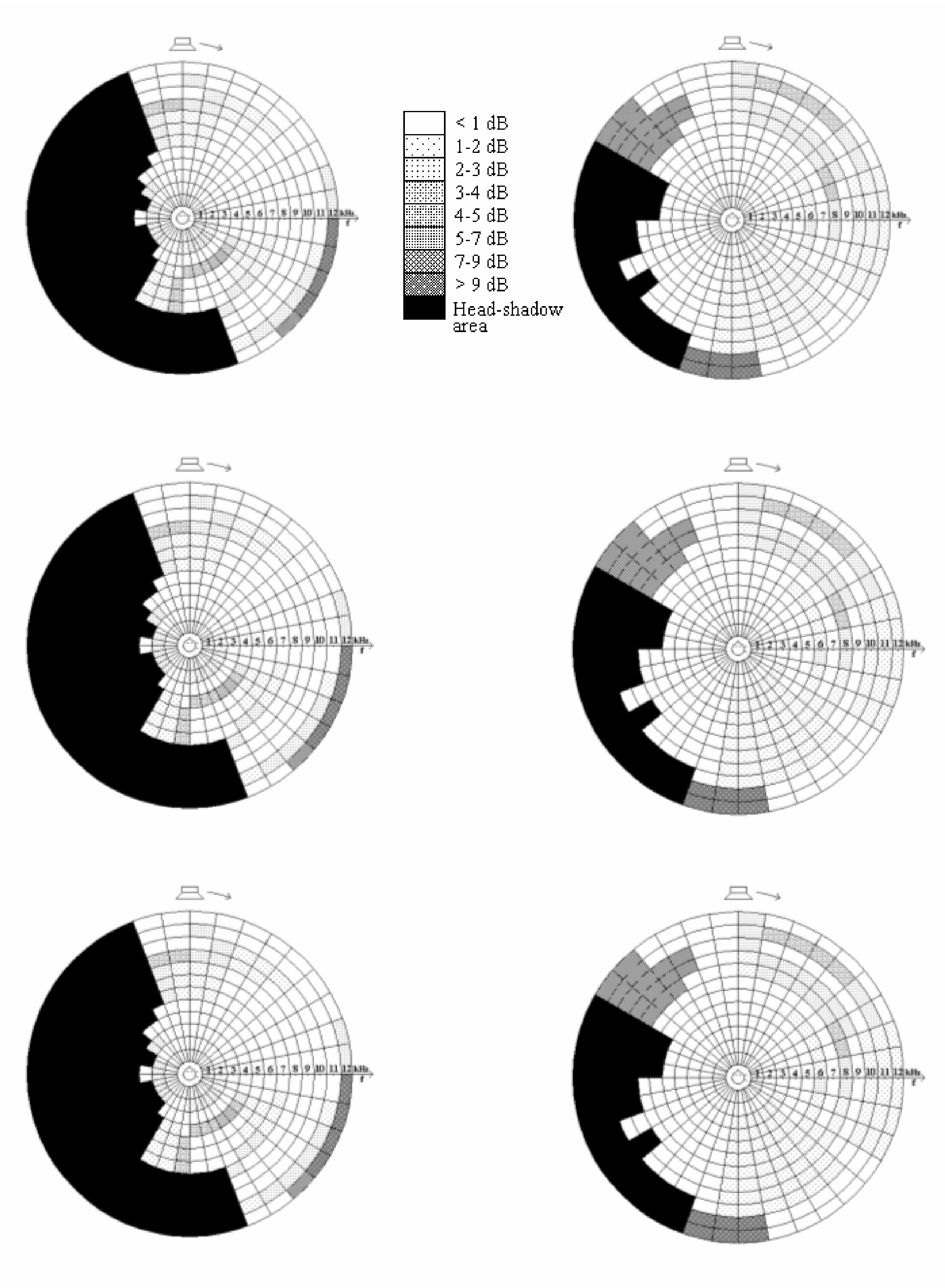

Figure 3: HRTFDs showing the effect of hair (above), baseball cap (middle) and glasses (below) from the elevation+30° (left column) and +60° (right column)

3 Measurement and results

The resolution of the measurement is 1° horizontal and 10° elevational from –10° up to +60°. Now we show averaged results for six different elevational positions for three objects (Fig.1-3). The objects we have been focused on are: four different kinds of glasses, four different but similar baseball caps and three toupees with different length and haircut. All of these objects are quite symmetrical and we made the effort to put them symmetrically to the median plane. The short-cut hair toupee was placed always without covering the pinnae and the long-cut hair always completely covering the pinnae. This fact did not influence the results at all.

Hair produces a broadband and significant effect, the most important domain is around 4-5 kHz, where the differences are large and permanent as the source is moving in the horizontal plane independent of the elevational position. Glasses are small, thin objects, they influence the HRTFs at higher frequencies. The following high frequency components are mainly influenced: 9, 10, 11 kHz. Because of the shadowing effect of the visor of the baseball cap above +20° elevation, the HRTFs vary too rapidly and random to evaluate components above 8 kHz. The domains at 3, 4-6, 7, 9, and 12 kHz are mainly disturbed, but the head-shadow area is not influenced very much.

During the evaluation of the results we did not observe any significant differences among the different kinds of caps, toupees or glasses. These objects have common properties and thus common effects on the HRTFs, which are represented by the HRTFDs. We present figures containing the averaged effects only for one ear (right ear).

Effect of the objects can be both amplification and damping, and they influence not only the height of existing peaks and valleys. They produce new frequency components and shifting in frequency as well.

The black-filled area on Figures 1-3 is the so-called head-shadow area where only low-frequency domains are available for spectral evaluation. Losing high frequency information leads to decreased localization performance of sources on the contralateral side. The evaluation of acoustical information outside the head-shadow area is made in the entire frequency range and inside only for the low-frequency components. As a general rule, we never found changes under 1600 Hz as expected [2, 12].

3.1 Binaural evaluation

Objects near to the head from our everyday life affect the acoustical environment and have clear and large influence on the HRTFs (exceeding 10 dB), although we do not recognize any differences and decrease of the localization performance in real-life situations. The hearing system is able to extract and decode the directional information from the sound waves even if the HRTFs vary randomly and rapidly. HRTFs seem to be important only in reducing the ambiguity as a basic pre-filtering effect.

Our measurement showed that HRTFs are not the critical point of the localization under free-field conditions and even in a virtual environment the headphone errors (the playback medium itself) could be more significant than the HRTFs [5].

In the median plane HRTFs are the basic cues, but small head movements are significant to avoid in-the-head localization and front-back confusions [14, 15]. These are more important than having “accurate” HRTFs.

4 Summary

Objects near the head have different effects in a wide frequency range. Glasses have the smallest effects, because they are thin and cause rather high frequency responses. On the other hand, hair always has influence and caps only in the region where shadowing effects occur (due to the visor). We assume that the most undesired effect for the hearing system is the extending of the shadowed area both in frequency and azimuth, because this can lead to localization errors by losing high frequency information.

With help of the HRTFDs differences of 1-10 dB were evaluated in dummy-head HRTFs. While virtual audio synthesis suffers from decreased localization performance due to the variations of the implemented HRTFs, free-field listening in real life environments does not require “stable” HRTFs. The acoustical environment near or on the head influences the HRTFs very much, without having a significant effect on the localization. This supports the importance of other localization cues such as head-movements or room reverberations in virtual audio synthesis instead of getting more “accurate” HRTF reproduction.

5 Future works

Future works include listening tests using measured HRTF data in order to determine the significance of these changes of the HRTFs caused by the environment near the head in virtual audio synthesis.

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