

# The role of head movement in the analysis of spatial impression

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## Background

We have developed a number of computational models of binaural hearing that can predict the perceived spatial attributes of a sound, including its location and dimensions. These have been used to make evaluations of a wide range of acoustical environments or systems, such as concert halls, sound reproduction systems, virtual acoustic environments, computer game audio systems, and low bit-rate audio codecs. Use of such models in development or final evaluation can both improve the quality of products and reduce development costs.

There are a number of issues that need to be considered when applying these binaural models to the measurement of such systems, including:

- development of suitable test signals;
- analysis of results in a perceptually meaningful manner, including uncovering the relationships with quality and preference;
- development of capture techniques that are practical and represent the behaviour of human listeners.

This project focused on the development of binaural capture techniques. Previously, signals captured for analysis by binaural models usually only considered a single position. However, listeners are rarely fixed in position, and movement can make a large difference to the perceived result. Therefore, research was undertaken to investigate the role of head movement in the analysis of spatial impression.

## Research questions

The research investigated three main questions related to head movements.

1. What head movements do listeners make in various situations?
2. How can we capture appropriate signals to take this into account for analysis?
3. What is the perceived effect of the results of measurements made including head movement?

## What head movements do listeners make?

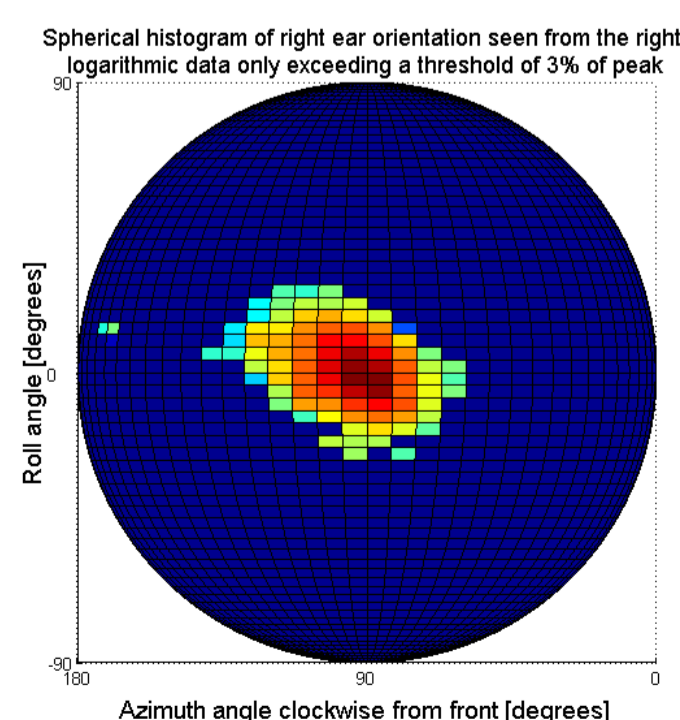
An experiment was undertaken to determine:

- the range and pattern of head movements made by listeners;
- whether the movements were dependent on the listening task;
- where binaural microphones need to be positioned to capture relevant signals for analysis.

In order to investigate this, the head movements of listeners were tracked whilst they undertook judgements of perceived location, source width, envelopment and timbre of a wide range of stimuli.

### Main outcomes

- The range of rotational movement by the listeners spanned the following:
  - Azimuth: -31.5° to 44.2°, Elevation: -9.4° to 15.5°, Roll: -14.9° to 12.3°.
- The movement range was dependent on task, with most for judgements of source width and envelopment, less for location, and little movement for timbre.
- The pattern of movement covered an area as shown in Figure 1 below.



**Figure 1: Spherical histogram showing the distribution of positions of the right ear for all stimuli and listening tasks.**

## How can we capture appropriate signals to take head movements into account?

Two main approaches were considered:

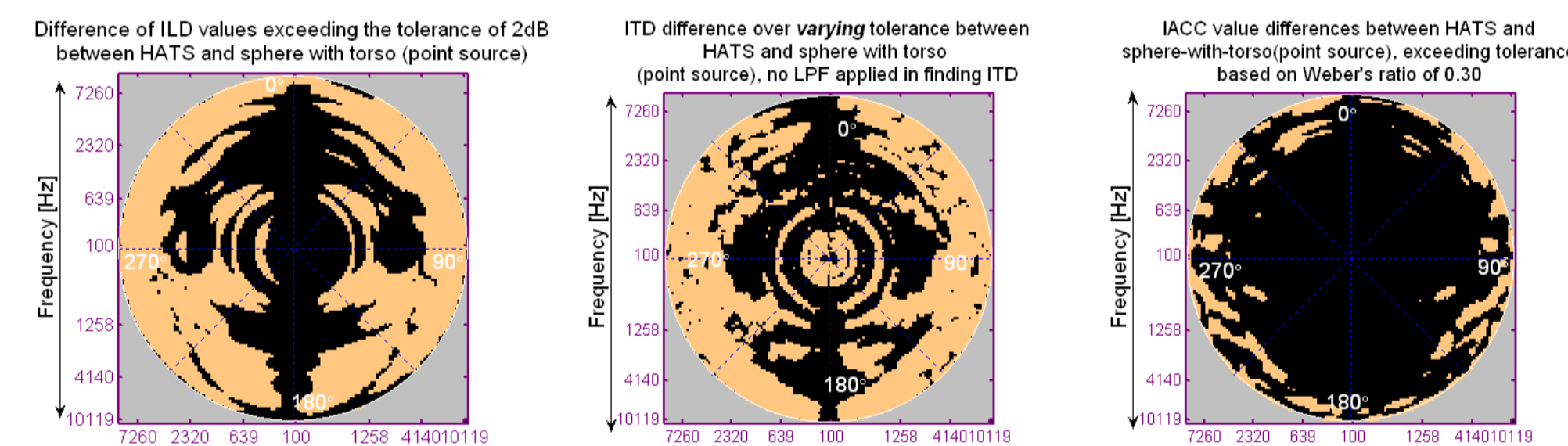
- placement and repeated movement of a head and torso simulator (HATS);
- multiple 'ears' in a simpler model of a head.

The former is more accurate, but takes much more time to capture the signals; the latter is more rapid (therefore more practical), but is less accurate.

Research was undertaken to evaluate the perceptual magnitude of the differences between measurements made using the HATS and a pair of omnidirectional microphones in a head-sized sphere.

### Main outcomes

- Perceptually motivated tolerances were derived from results of just-noticeable difference studies - in many cases this included calculating reference-dependent thresholds.
- The addition of a torso to the sphere improves the accuracy of the results.
- The addition of smaller features to the sphere (such as nose and pinnae) had little effect.
- The accuracy of interaural time difference measurements was good in some areas.
- The accuracy of interaural level difference measurements was good below c. 1kHz.
- The accuracy of both these parameters was good enough to accurately predict the perceived location for a specifically tailored binaural model.
- The accuracy of interaural cross-correlation coefficient was generally good.



**Figure 2: Results of measurement differences above (pale) and below threshold (black) between the HATS and sphere with torso, for interaural level difference (left plot), interaural time difference (centre plot) and interaural cross-correlation coefficient (right plot).**

### Microphone spacing

Using a combination of spatial sampling theory and perceptually-motivated error tolerances, the spacing of the microphones around the sphere was optimised to reduce the number of necessary processing channels whilst still maintaining measurement accuracy. The microphones were laid out in a pattern based on the results of the previous research summarised in Figure 1.

A demonstration system was created and evaluated consisting of a sphere containing 20 omnidirectional microphones with a torso.

## Acknowledgements

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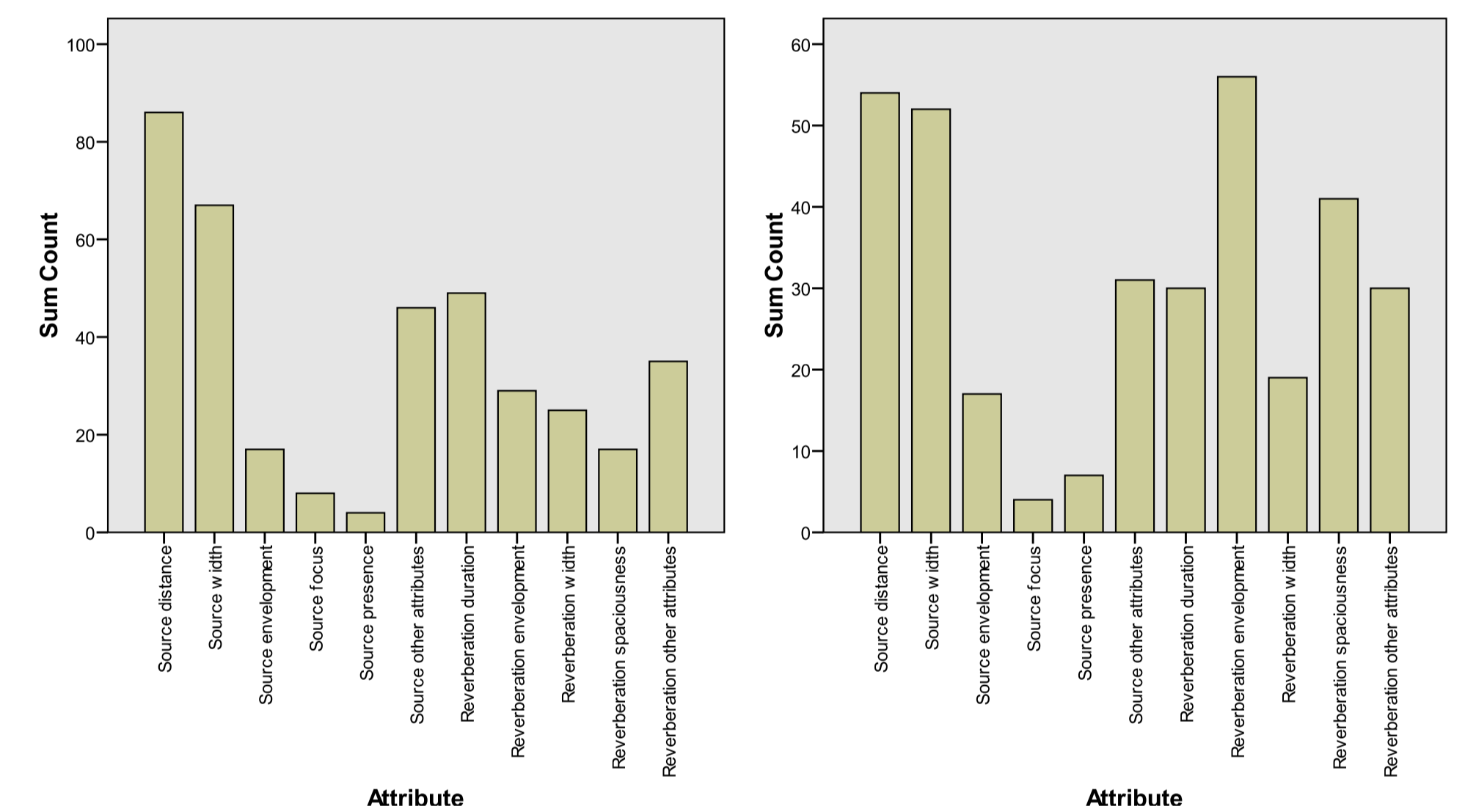
## What is the perceived effect of measurements made including head movement?

A series of experiments were undertaken to determine the perceived effect of position-dependent variations in interaural cross-correlation (IACC). This consisted of two elicitation stages:

- graphical elicitation, where the listeners drew the source and environment on a plan view;
- verbal elicitation, where the listeners described the differences in source and environment using word pairs.

### Main outcomes

- Variations in the IACC when facing forwards affected the source width, distance, and environment width.
- Variations in the IACC when facing sideways affected the environment depth, envelopment and spaciousness.



**Figure 3: Results of the verbal elicitation experiment for changes caused by variations in IACC at the front (left plot) and at the side (right plot).**

The results also showed that the listeners tended to use a 'scanning technique' in which the IACC affected the perceived width along the lateral plane auditioned.

In addition, methods for integrating the measured results from each pair of microphones were developed so that the position and dimensions of a sound can be displayed on a 360° plan view.

## Conclusions

This research project has successfully:

- determined the range and pattern of head movements that listeners make in a range of situations;
- developed a method for capturing binaural signals incorporating this head movement;
- developed a method for analysing the results of binaural analysis incorporating head movement;
- demonstrated the benefits of a measurement technique incorporating head movement over a conventional fixed measurement;
- created a practical demonstration system that has been employed to evaluate sound reproduction systems and acoustical environments.