Computational Perception

15-485/785

January 24, 2008

Sound Localization 3

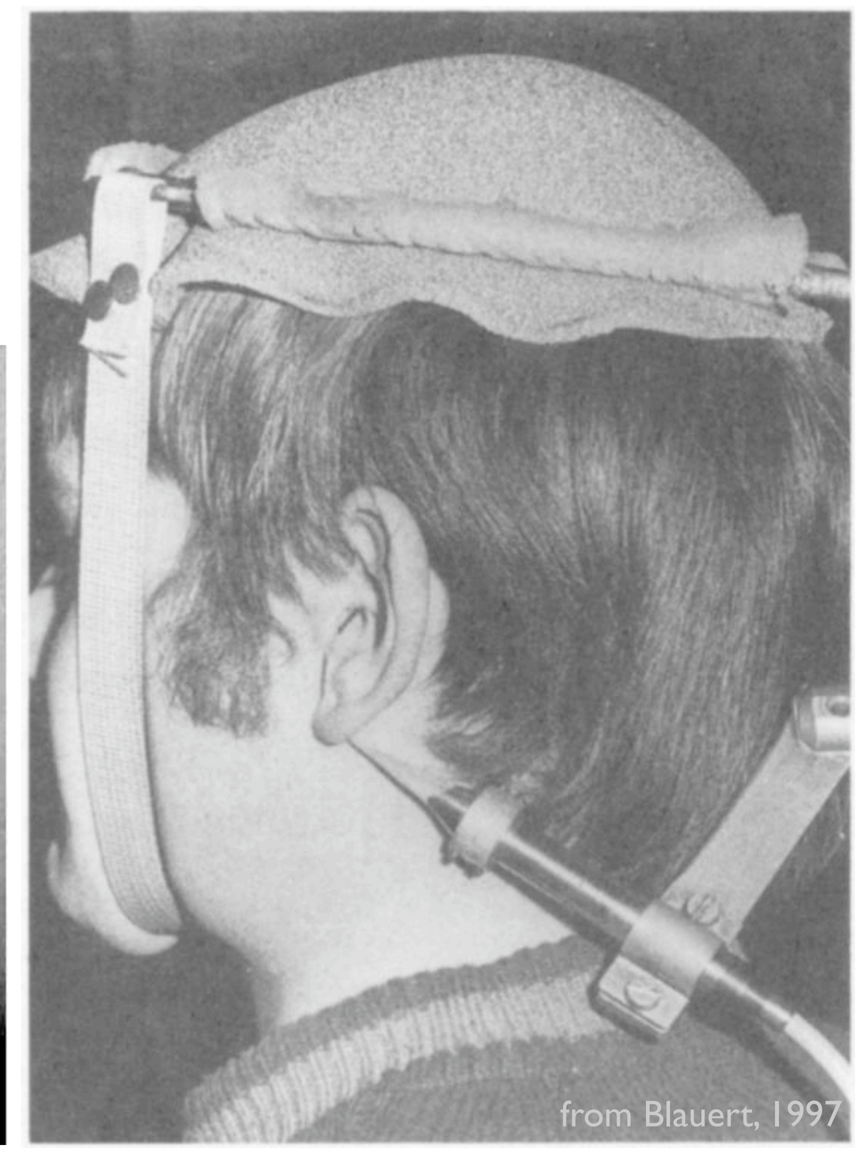
The general case

- What limitations do the pinnae measurements have?
  - Do not take into account the effect of the head and body.
- How to characterize the filtering?
  - Measure the transfer function: ratio of pressure at sound source to pressure of (ideally) sound reaching eardrum
  - this is called the *head-related transfer function* (HRTF)

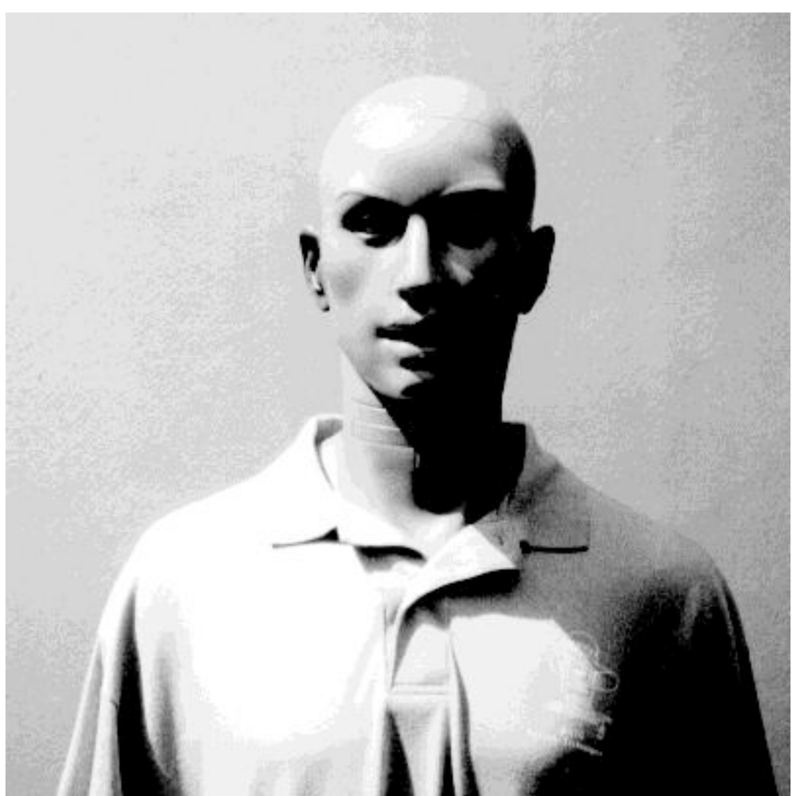
Measuring HRTFs

- Different types of HRTFs
  - monaural: pressure at source vs ear drum
  - binaural: pressure difference for two corresponding points in the ear canal

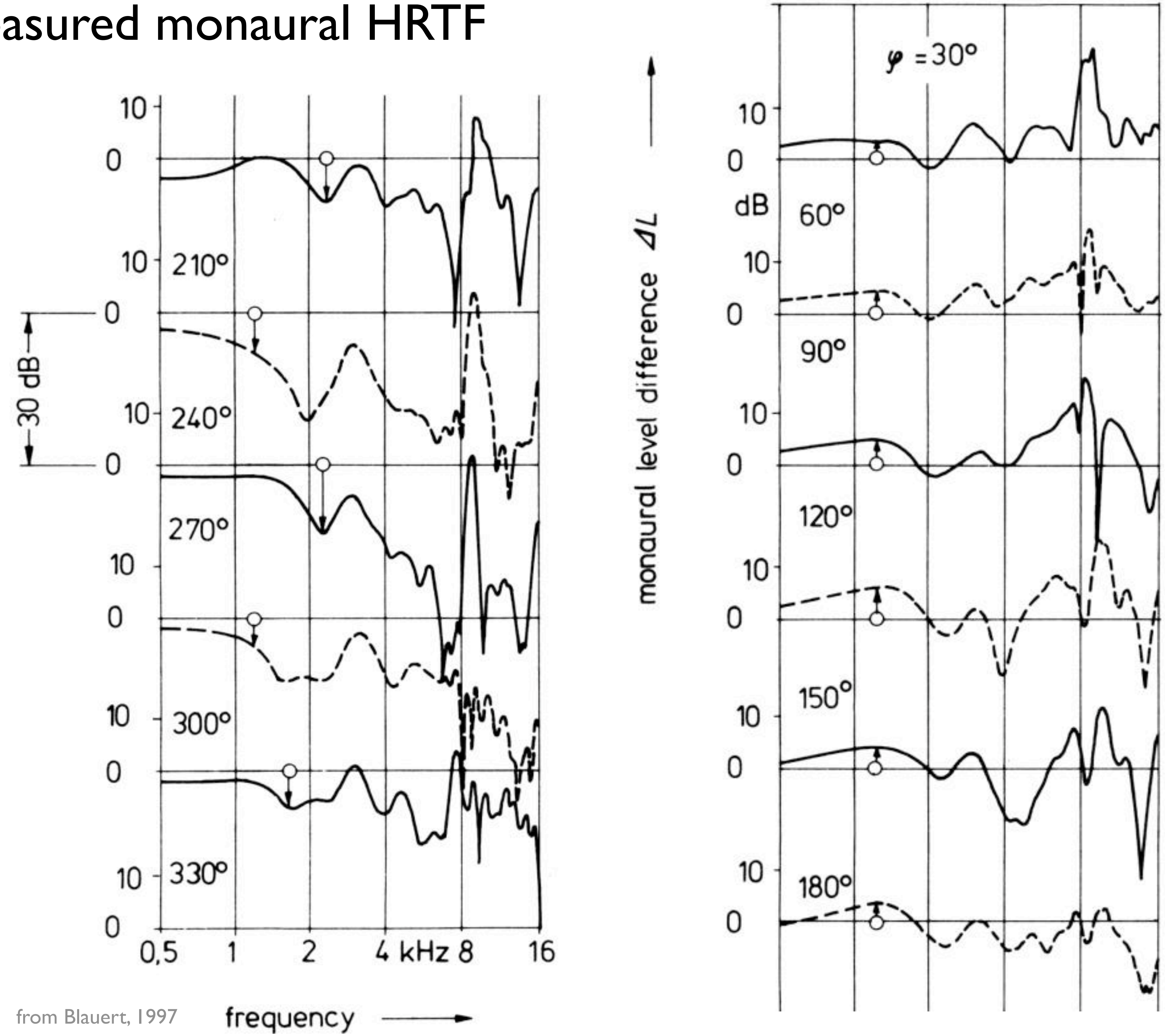
Subject with probe mics



Kemar the sound dummy



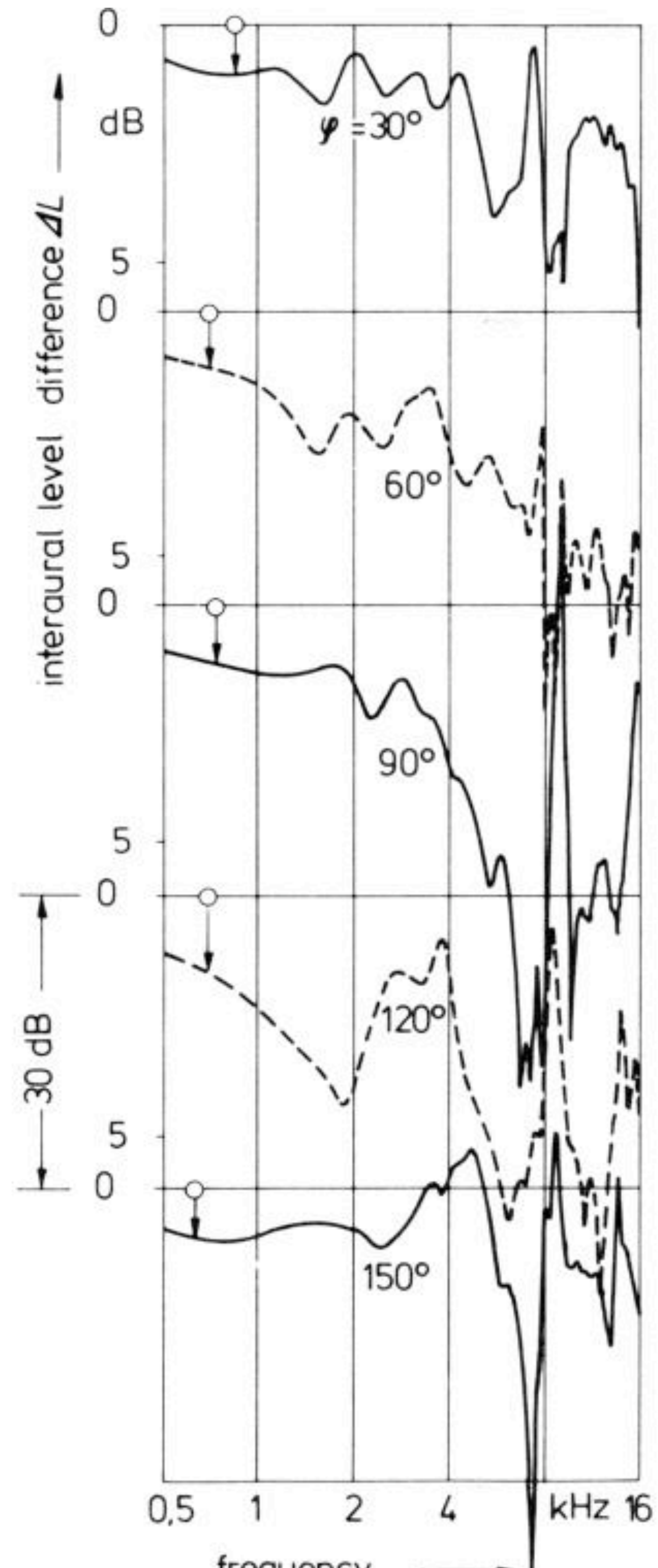
Measured monaural HRTF



from Blauert, 1997

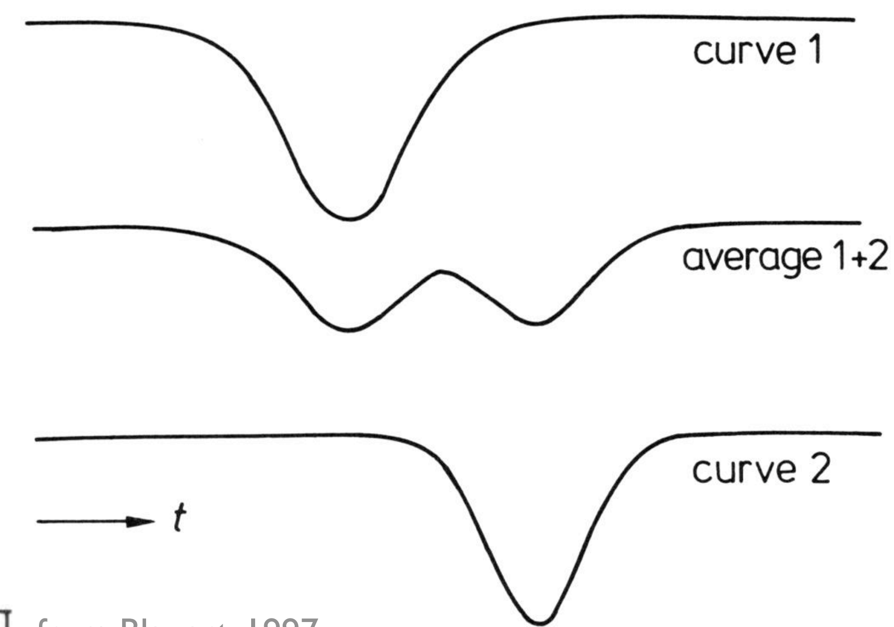
Measured binaural HRTF

from Blauert, 1997

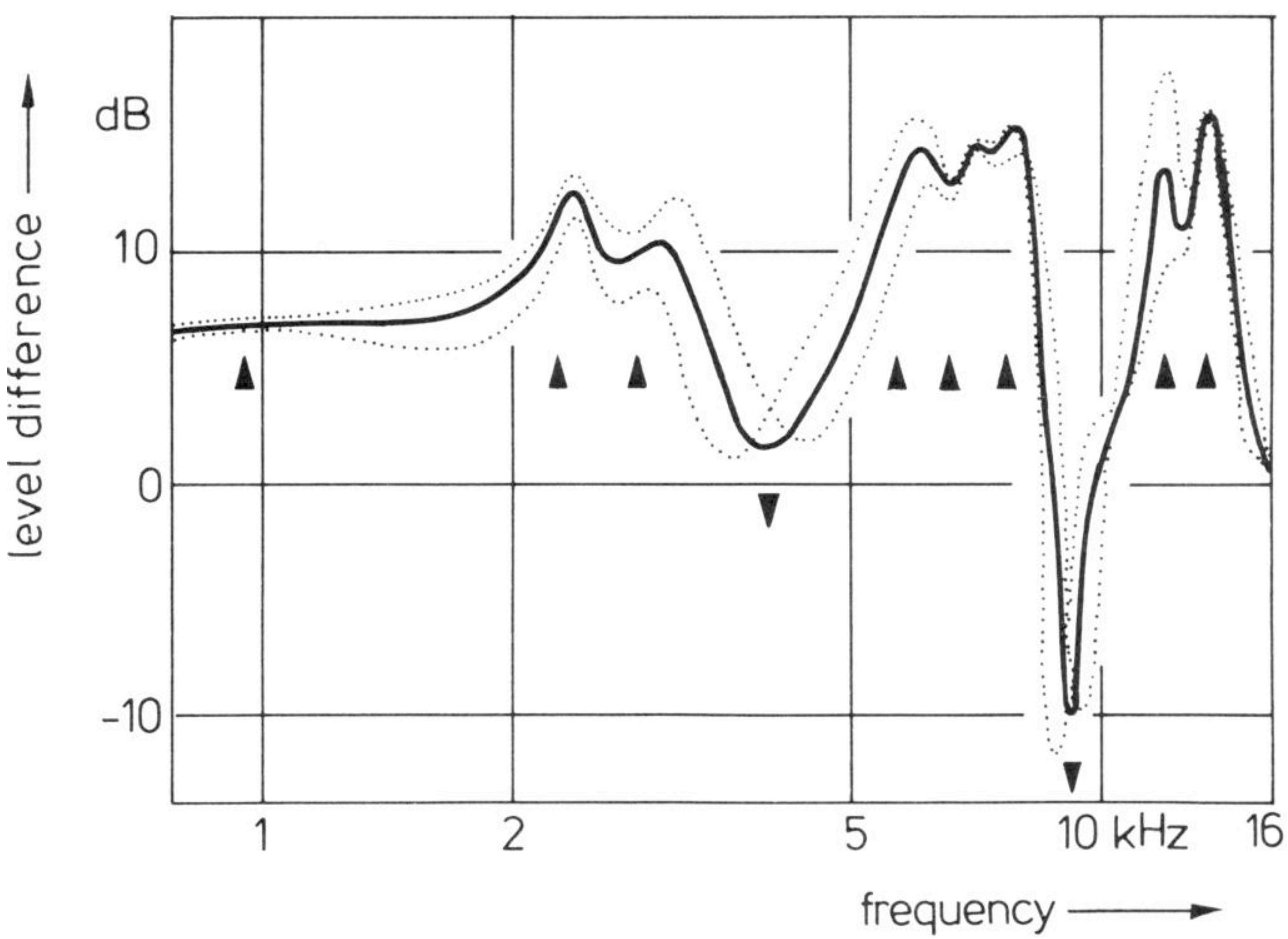


Problems in using HRTFs

- HRTFs vary across subjects
- can't easily get an "average"
- but can do "structural averaging"

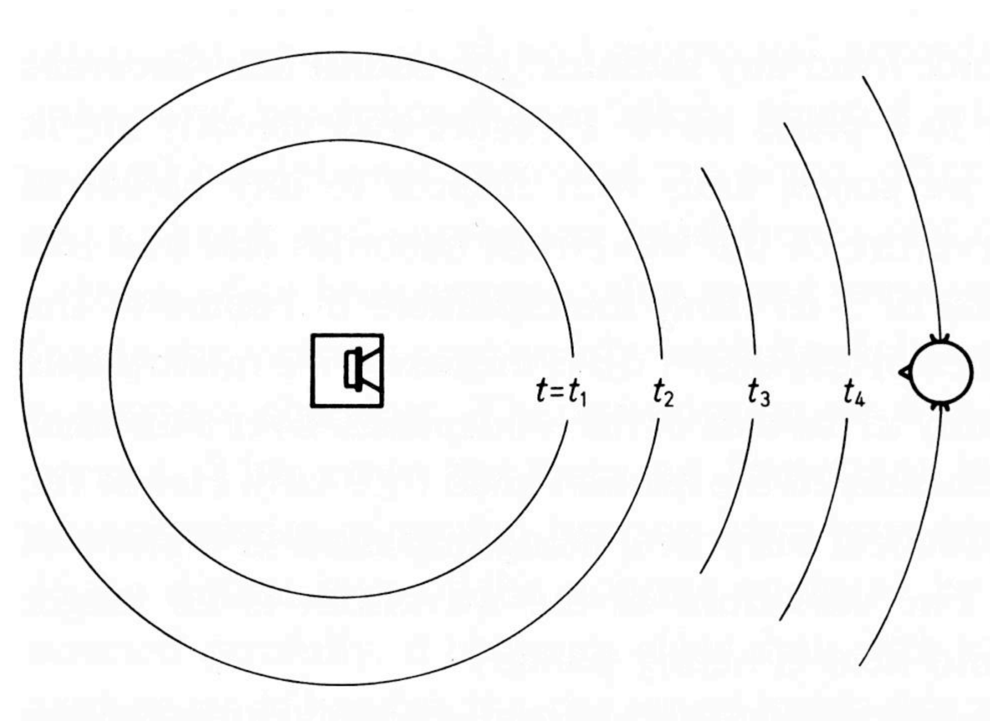


from Blauert, 1997



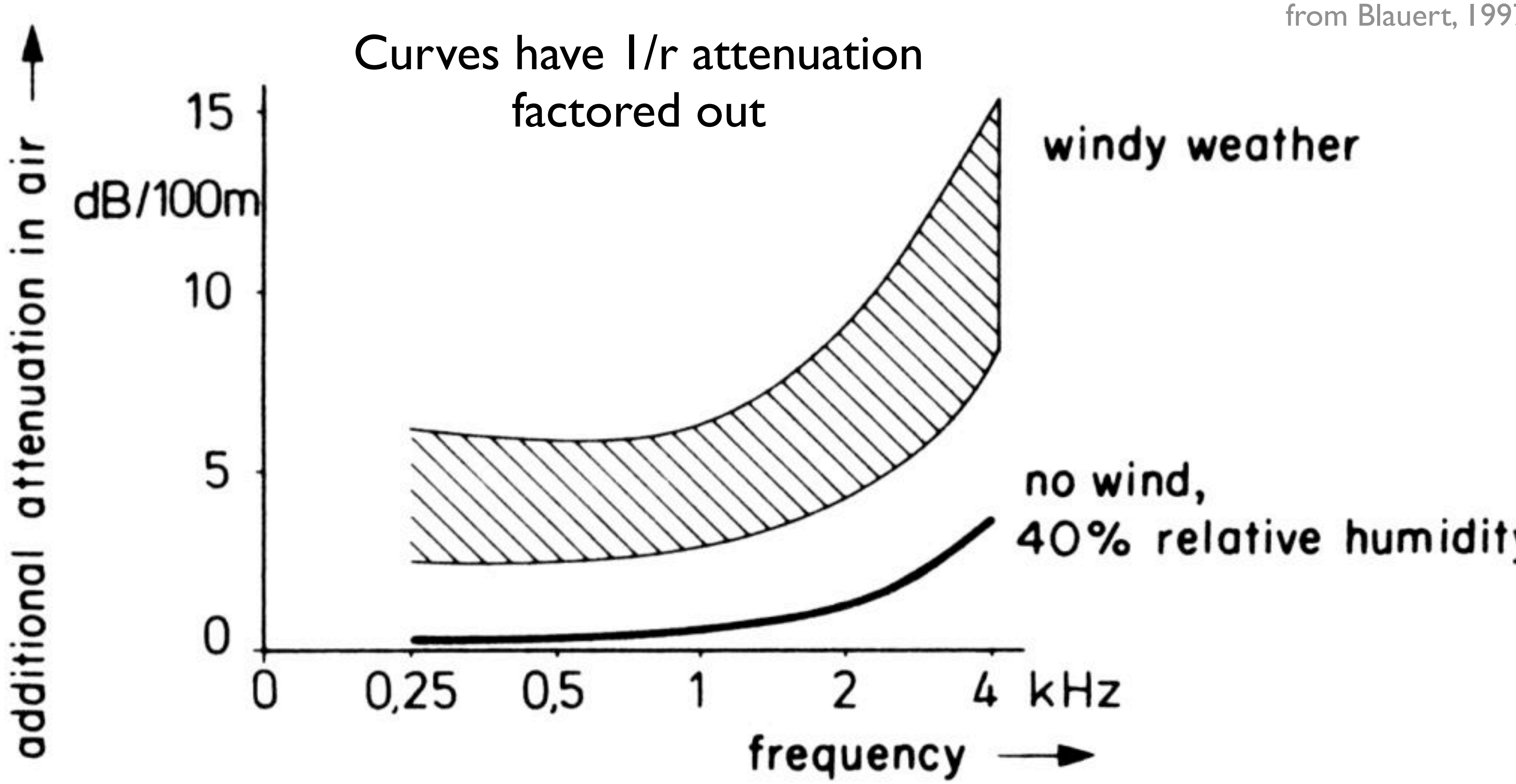
More than just direction: cues for sound distance

- Frequency independent 1/r
- pressure attenuation – works if you know some properties of sound source
- HRTF depends on distance
- freq. dependent attenuation (long distances)
- head movements (short distances)

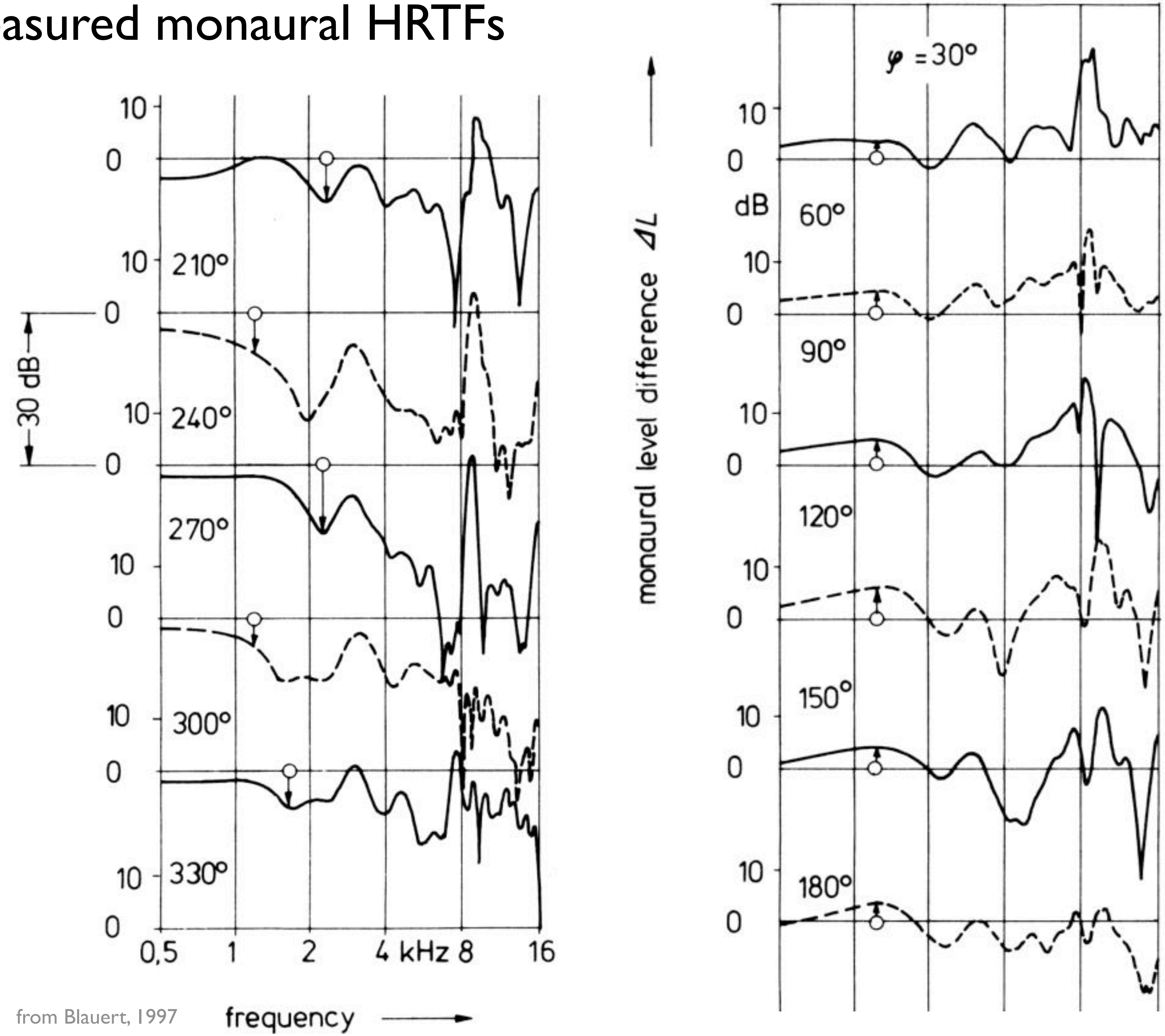


from Blauert, 1997

Curves have 1/r attenuation factored out



Measured monaural HRTFs



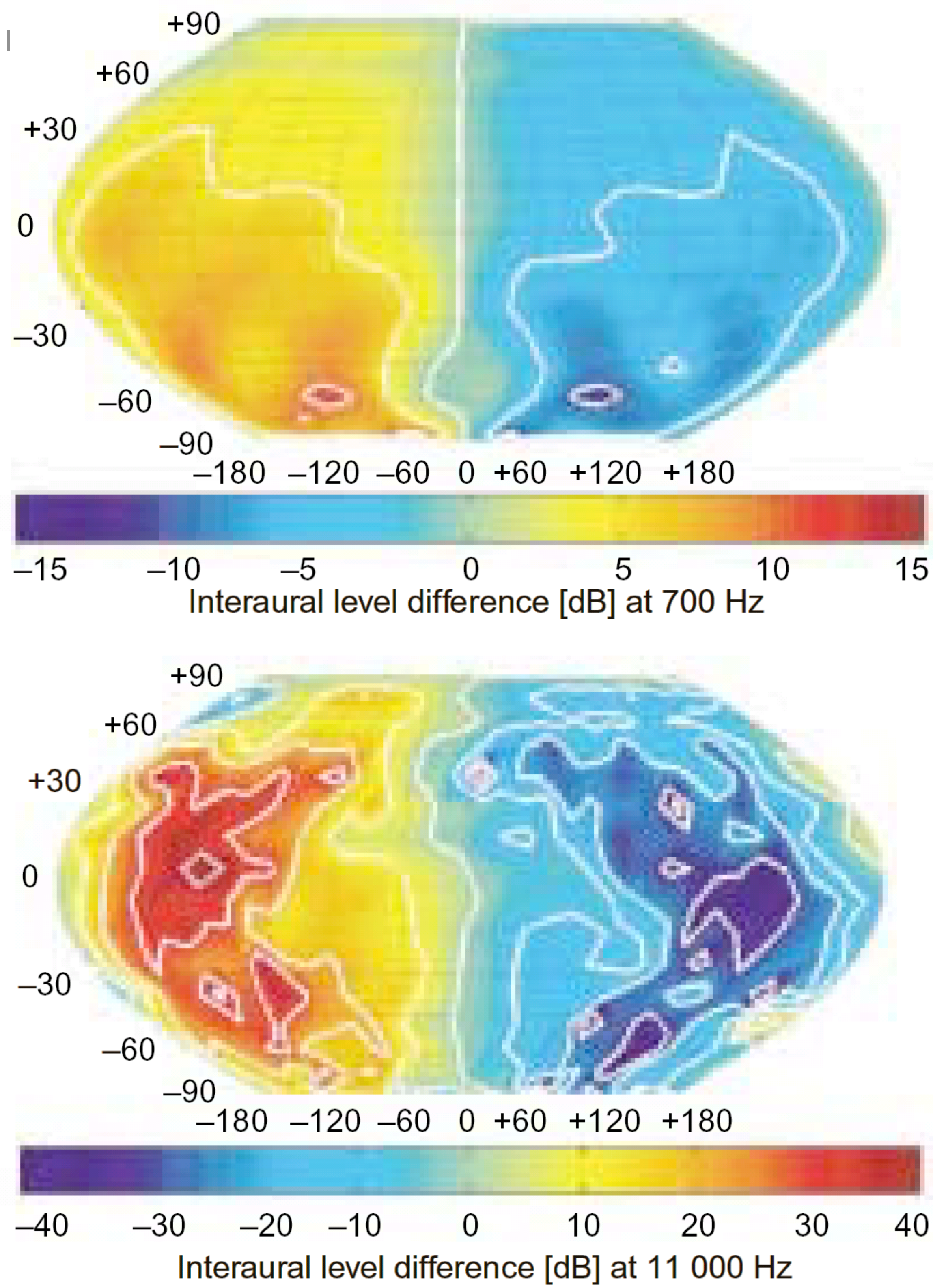
from Blauert, 1997

ILD Map: azimuth and elevation

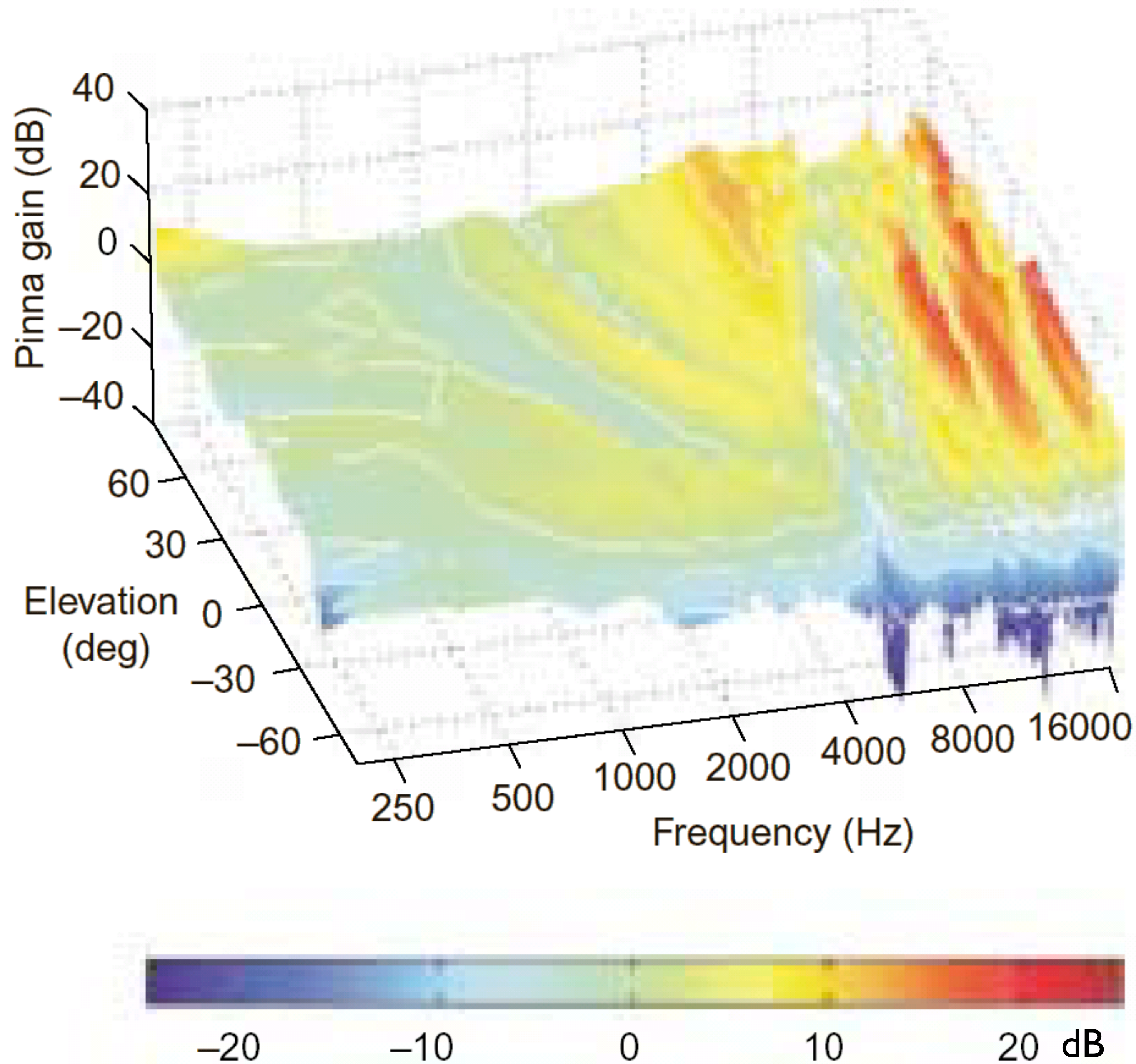
from King et al, 2001

700 Hz

11,000 Hz

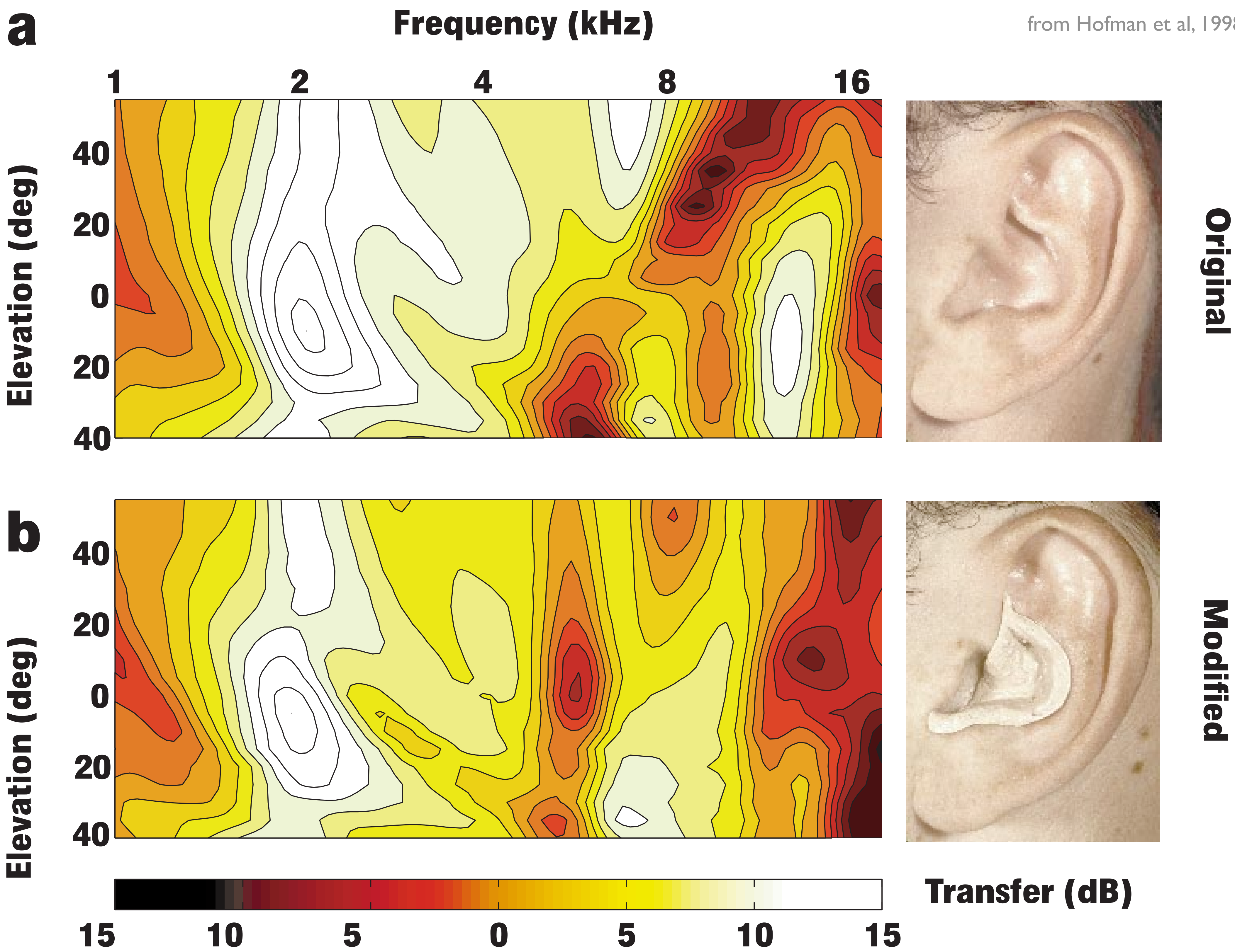


Pinna gain as a function of frequency



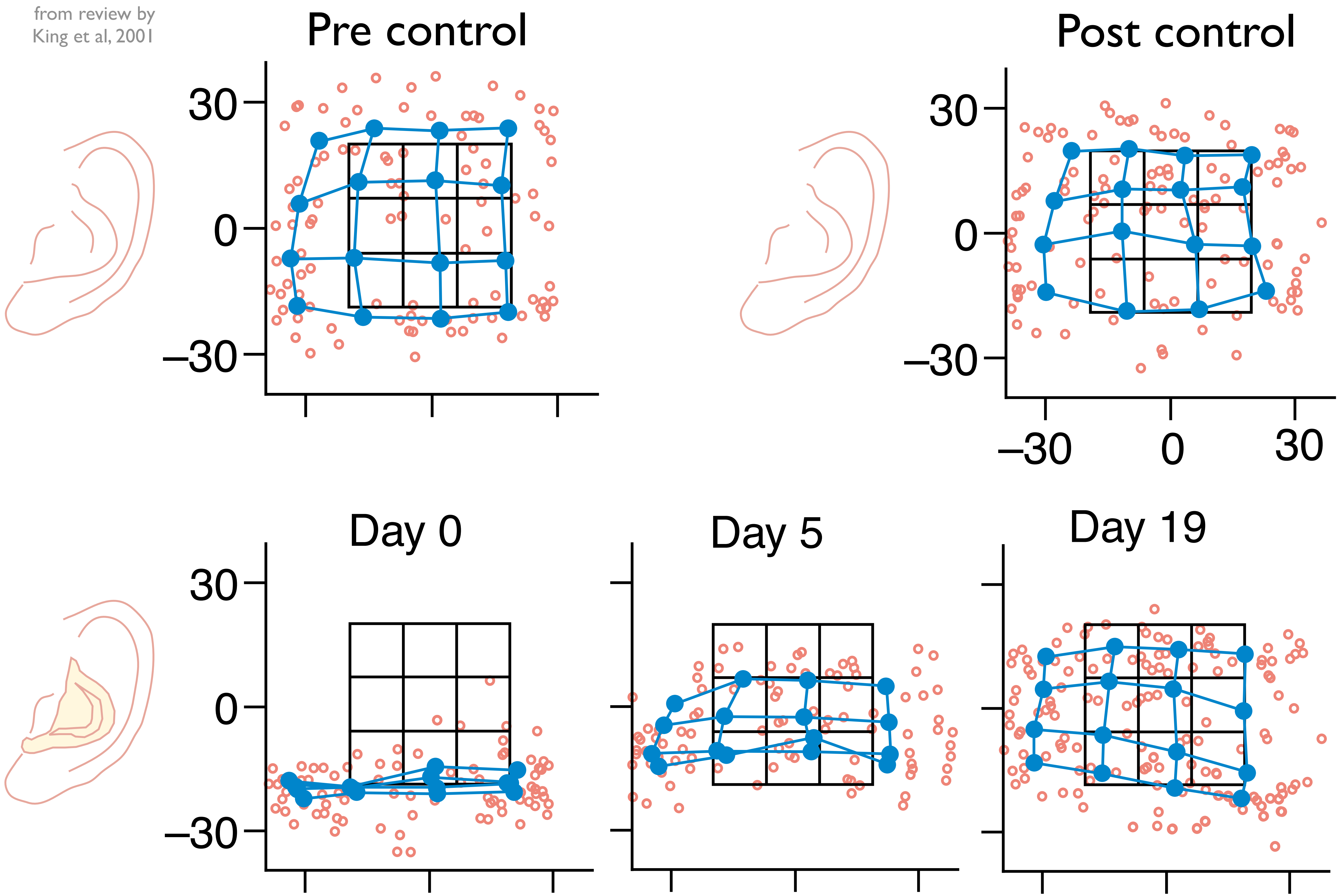
Ear goggles: Effect of molds on pinna acoustic transfer

from Hofman et al, 1998

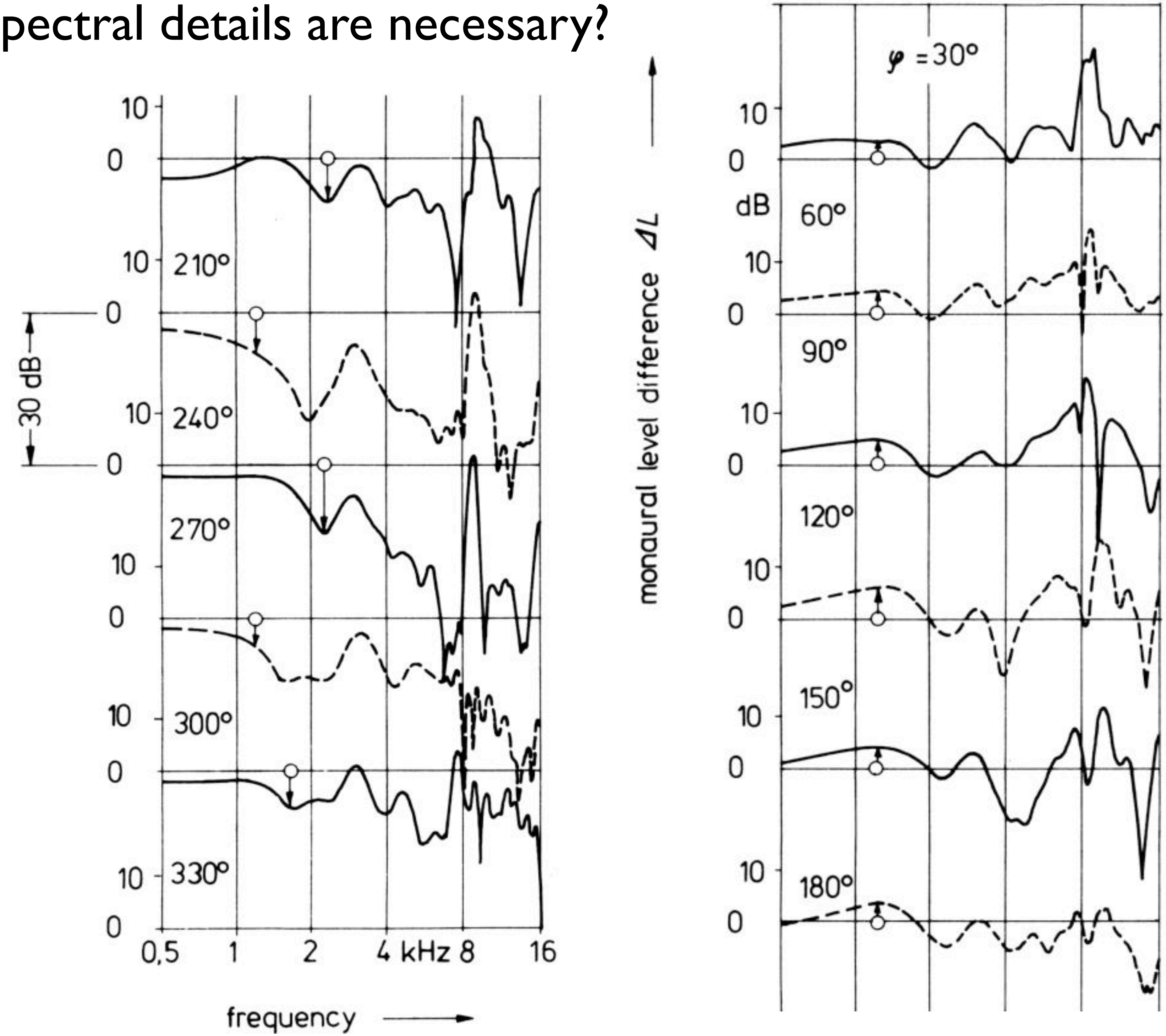


Hofman et al (1998)

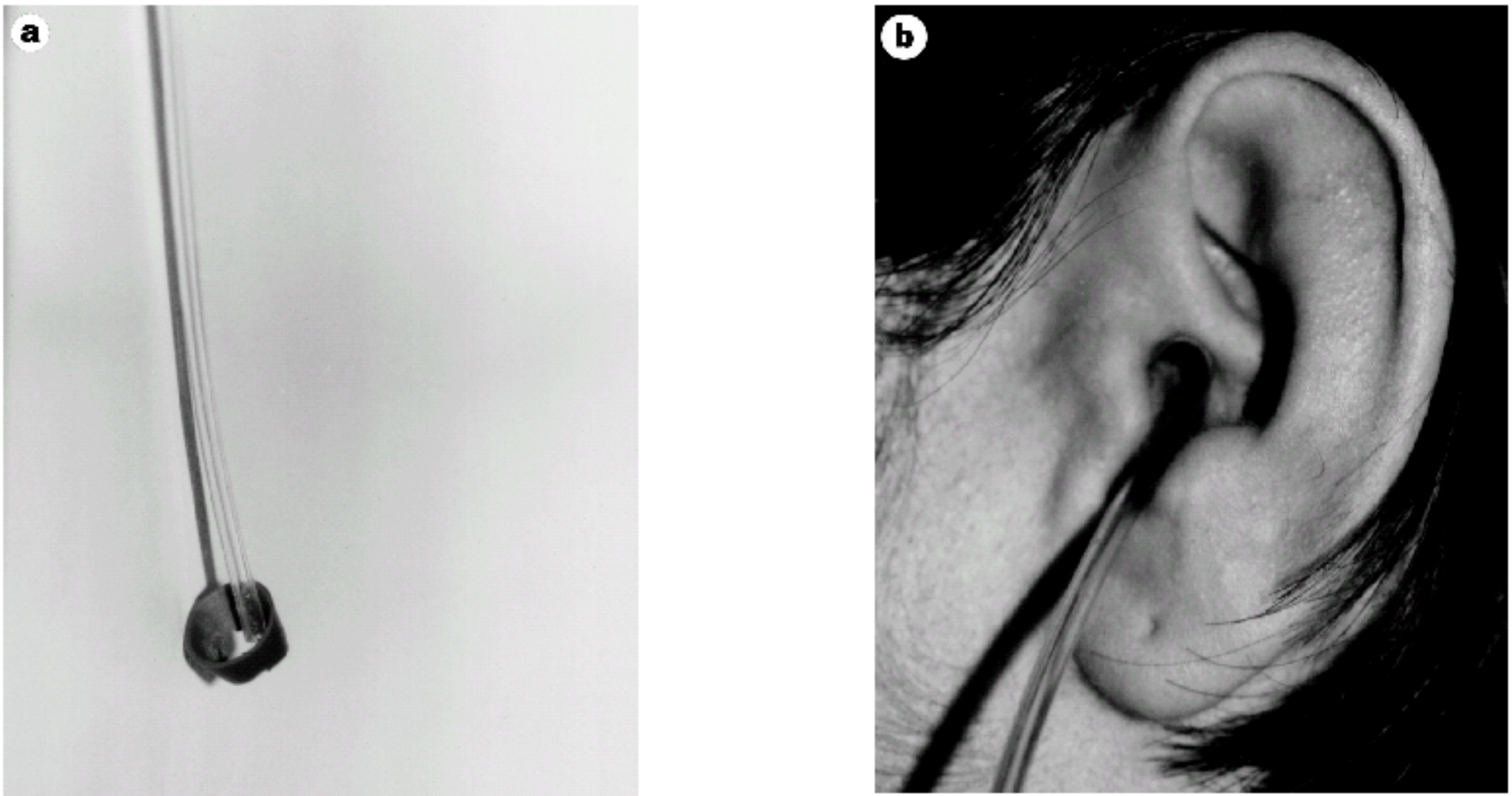
from review by
King et al, 2001



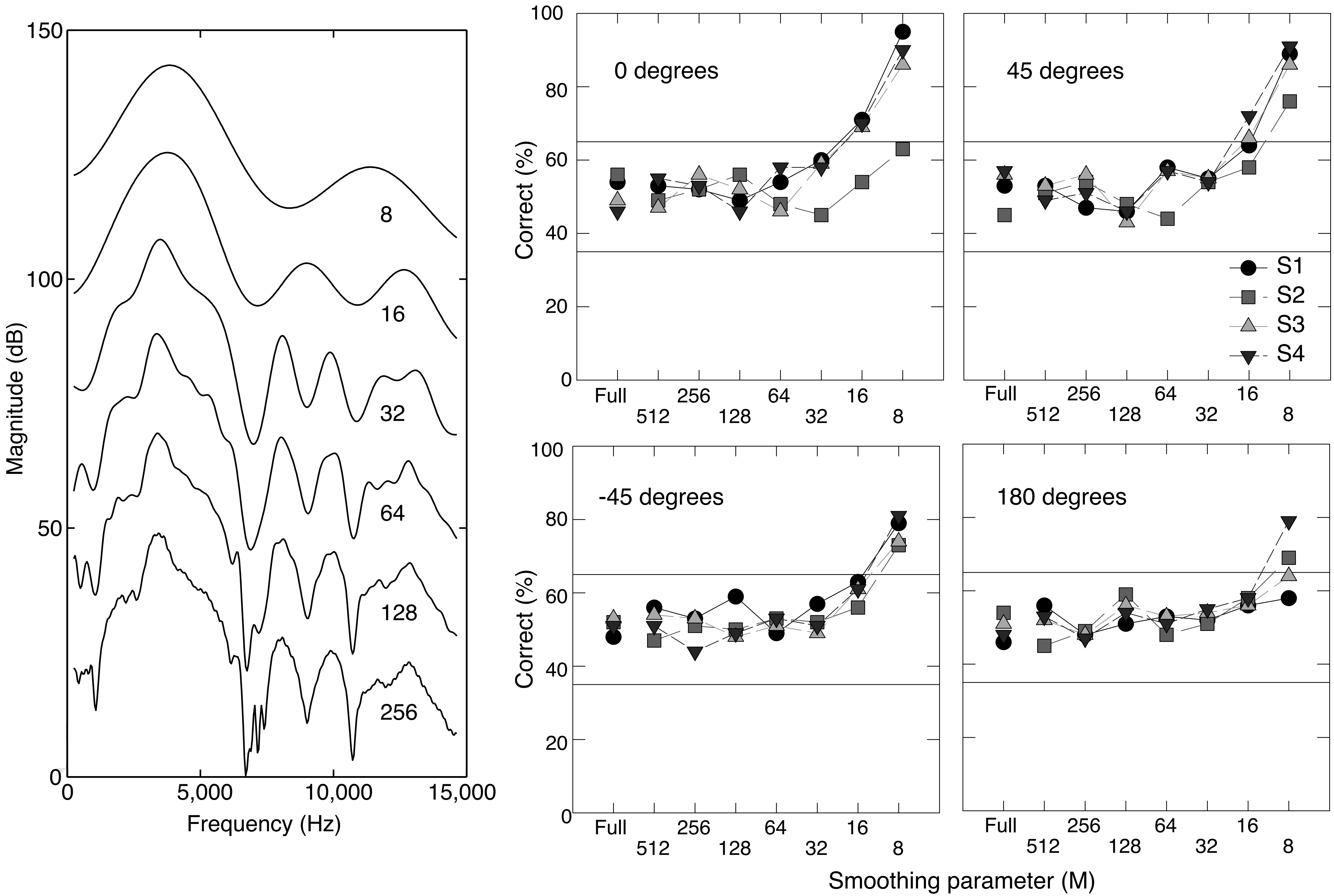
What spectral details are necessary?



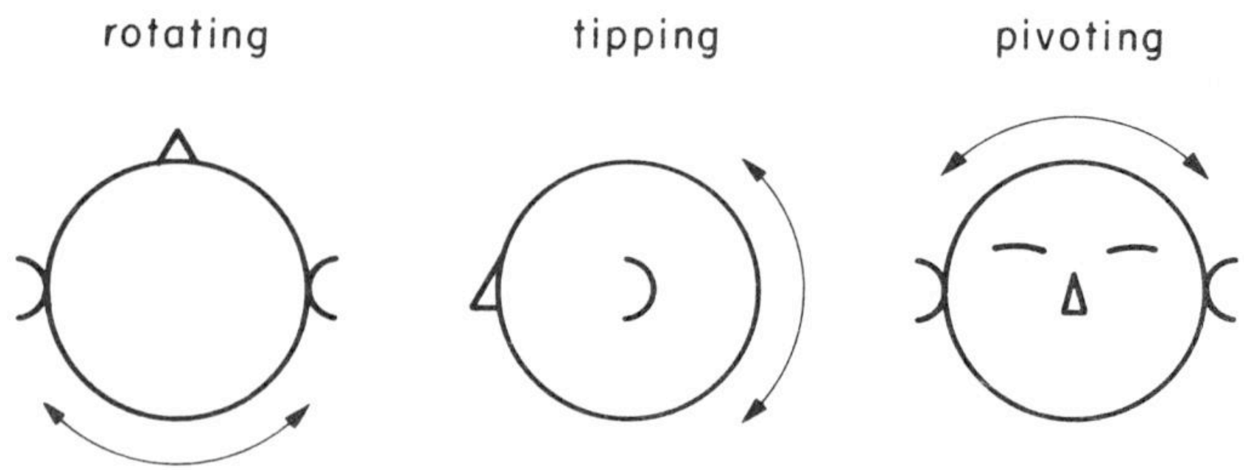
Role of spectral detail (Kulkarni and Colburn, 1998)



Spectral smoothing of HRTFs (Kulkarni and Colburn, 1998)

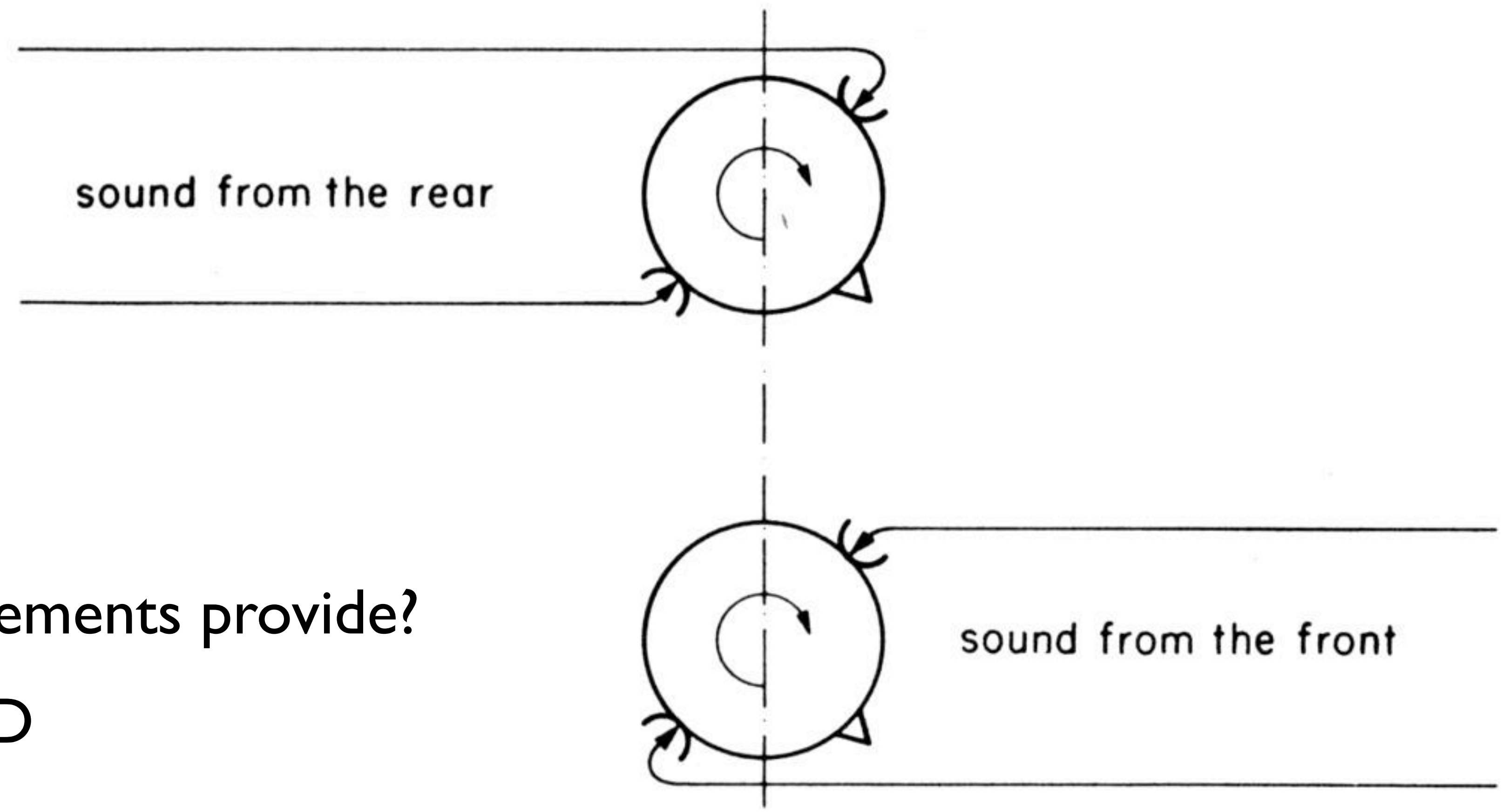


What about head movements?



How do we make front-back discriminations?

- pinna are asymmetric
- head movements

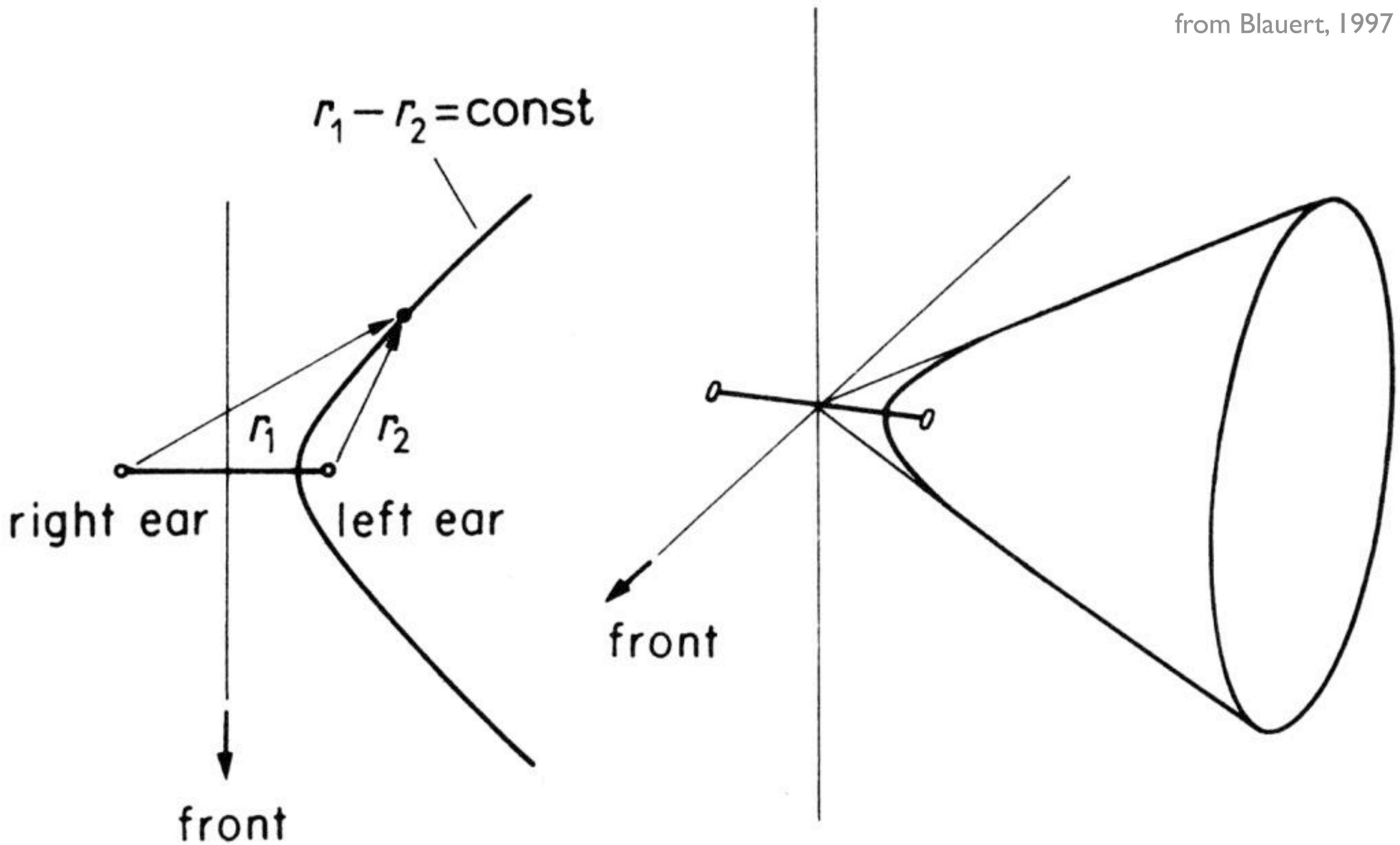


from Blauert, 1997

- What cues do head movements provide?
  - changes in ITD and IID
  - changes in sound spectrum

Cone of confusion

from Blauert, 1997



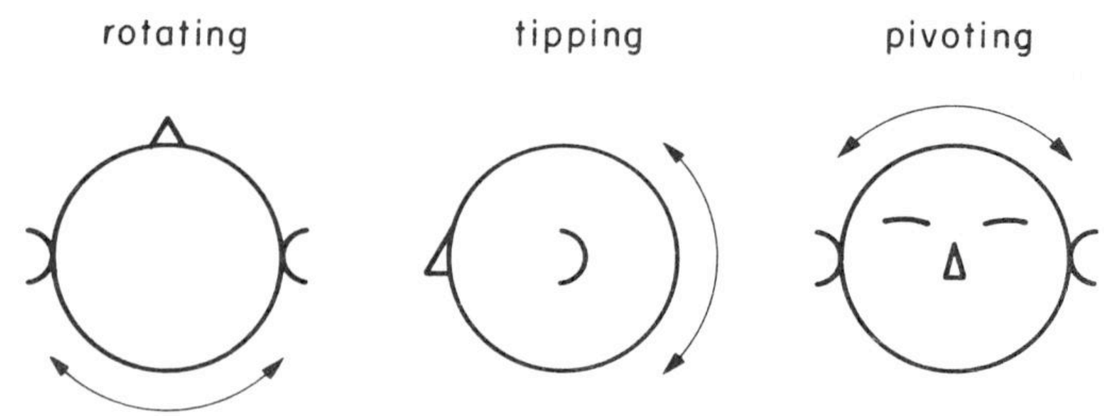
(a)

(b)

All points on cone are same relative distance to each each ear.

Evaluating the Role of Head Movements

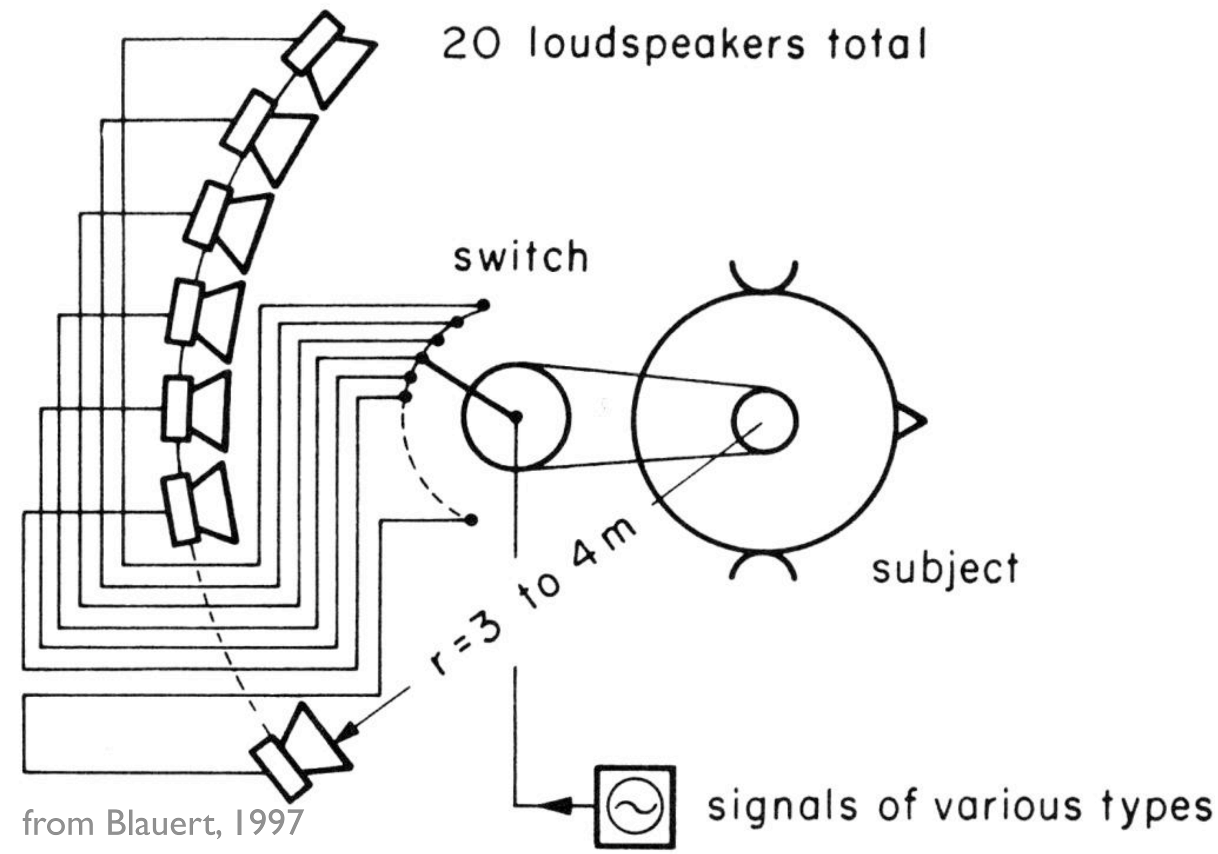
- Usually heads are immobilized in localization experts.
- Thurlow, Mangles, and Runge, 1967: test subjects ability to freely localize
  - 10 sound sources in anechoic chamber
  - subjects blind-folded
  - free to move head, but kept torso still
  - 500-700 Hz or 7.5-8 kHz



- Their observations:
  - Monaural can be as good as binaural if head movements are allowed.
  - First movement is to orient to (perceived) sound direction.
  - Most move their head back and forth more than once.
  - Most movements were rotations.
- What do head movements with headphone sounds say about the perception that the sound is in head?
  - *Inside is the only consistent location.*

Can head movements give you externalization?

- A Test by Wallach (1938; 1939)
  - sound moves with head
  - (almost) transient free switch
  - ratio between head movement and switch variable
- Speakers are behind subject's head, sound moves with the head.



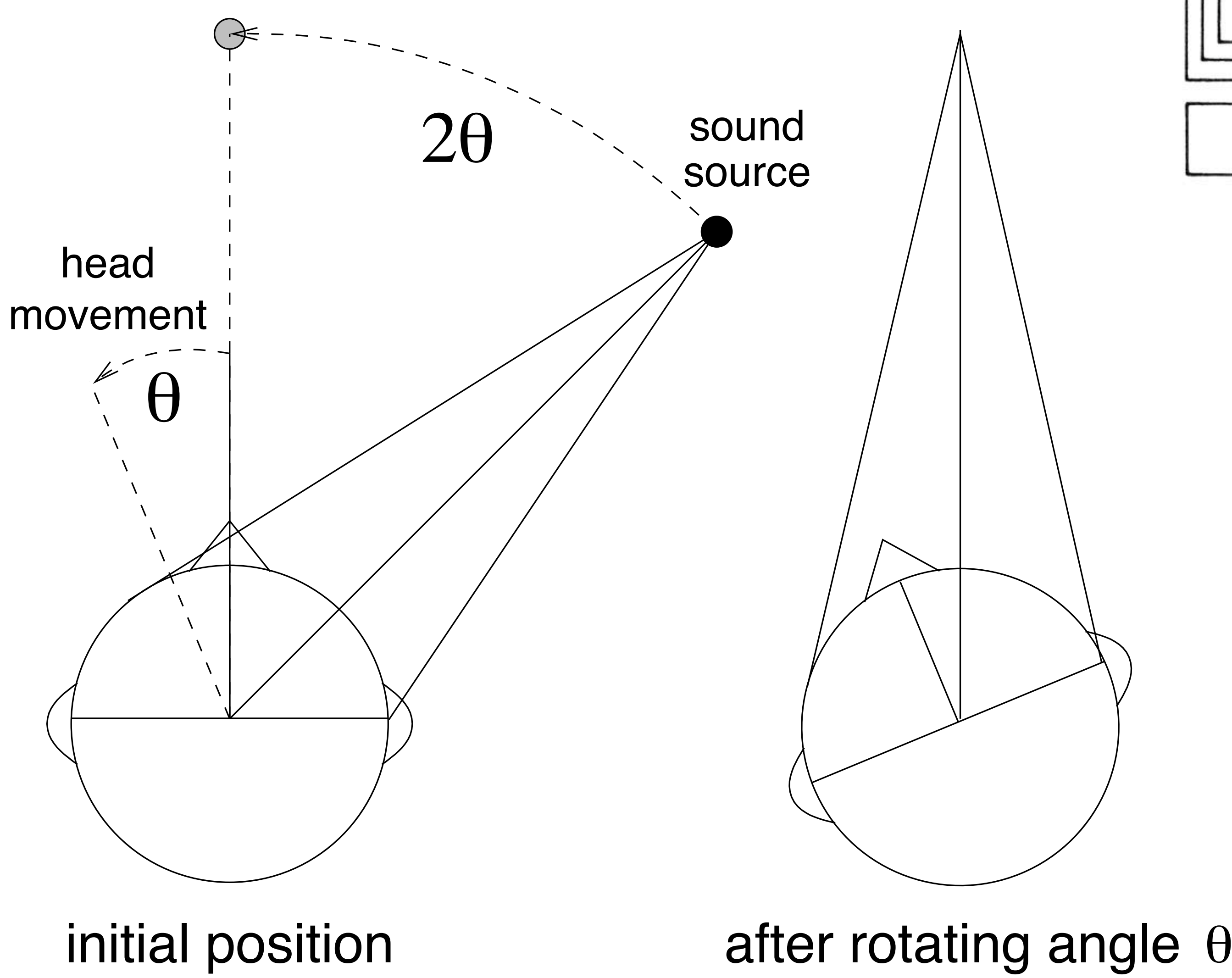
from Blauert, 1997

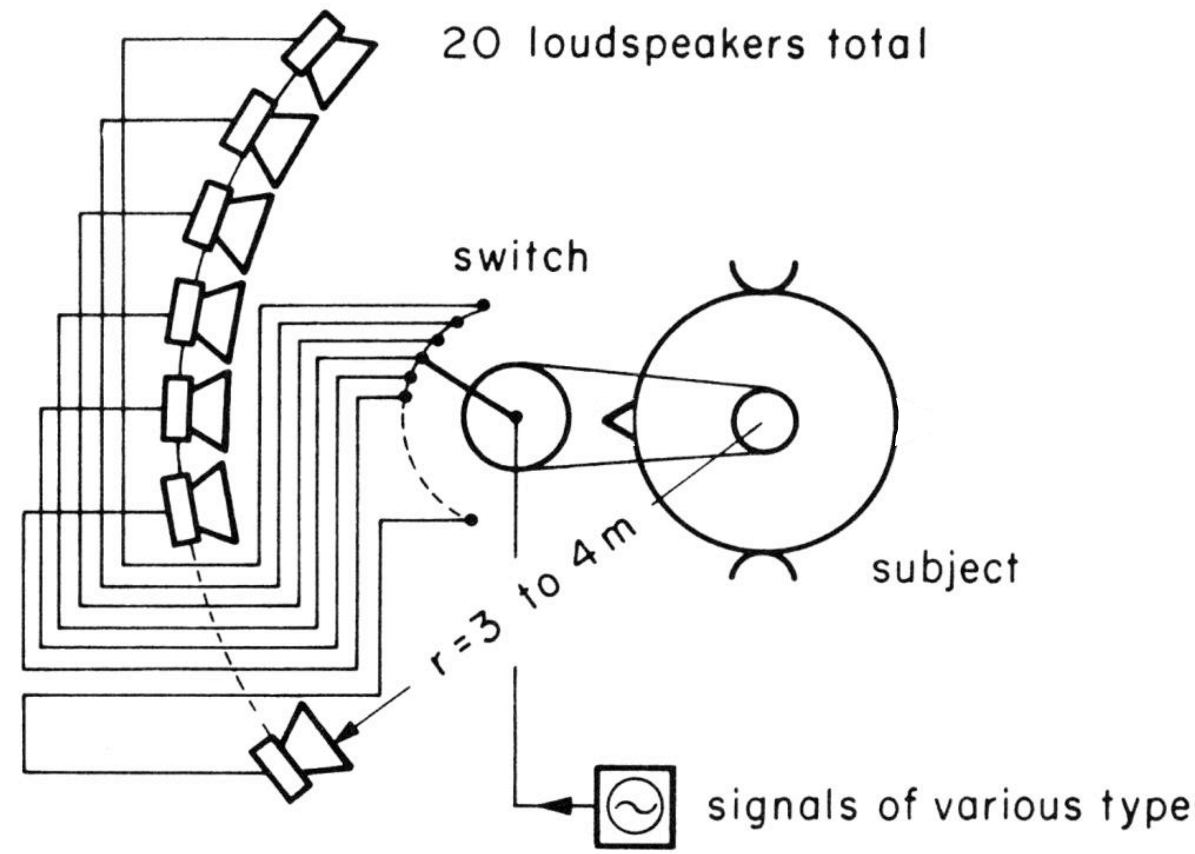
Where do subjects think the sound is?

Above (usually)

Another test of externalization

- Now speakers are in front, but sound moves at 2x head angle





Now where do subjects think the sound is?

Behind the head, in all 15 subjects.

The computational problem

Three general approaches:

1. Approximate analytic solutions:

   Simplify physics and solve for variables of interest

2. Empirical solutions:

   Measure sound field transformations and solve inverse problem

3. Adaptive solutions:

   Make minimal assumptions and estimate inverse function