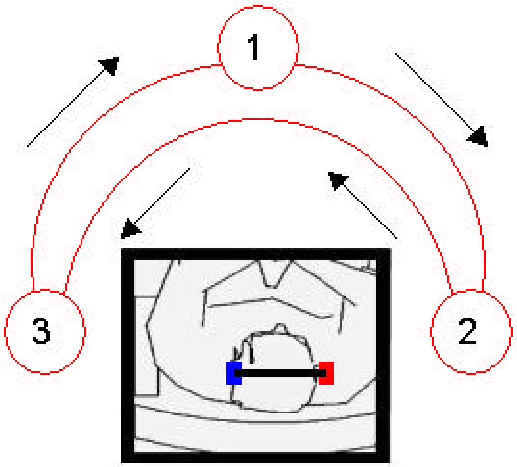
BINAURAL HEARING and INTELLIGIBILITY in AUDITORY DISPLAYS



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Human Factors Research & Technology Division

NASA Ames Research Center

Moffett Field, California

1. Binaural hearing phenomena

2. Newly developed auditory displays
   that exploit spatial hearing for improving

   - speech intelligibility
   - alarm intelligibility

   in aviation applications

Physical characteristics of sound and perceived attributes

- **F**requency → (perceived pitch)
- **I**ntensity → (loudness)
- **S**pectral content → (timbre)
- **FIS**, plus binaural differences → (localization)

Physical characteristics of sound and perceived attributes

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- **S**pectral content → (timbre)
- **FIS**, plus binaural differences → (localization)

** All characteristics are important in the identification and discrimination of auditory signals and for speech intelligibility in communication contexts

Two important functions of the binaural hearing system

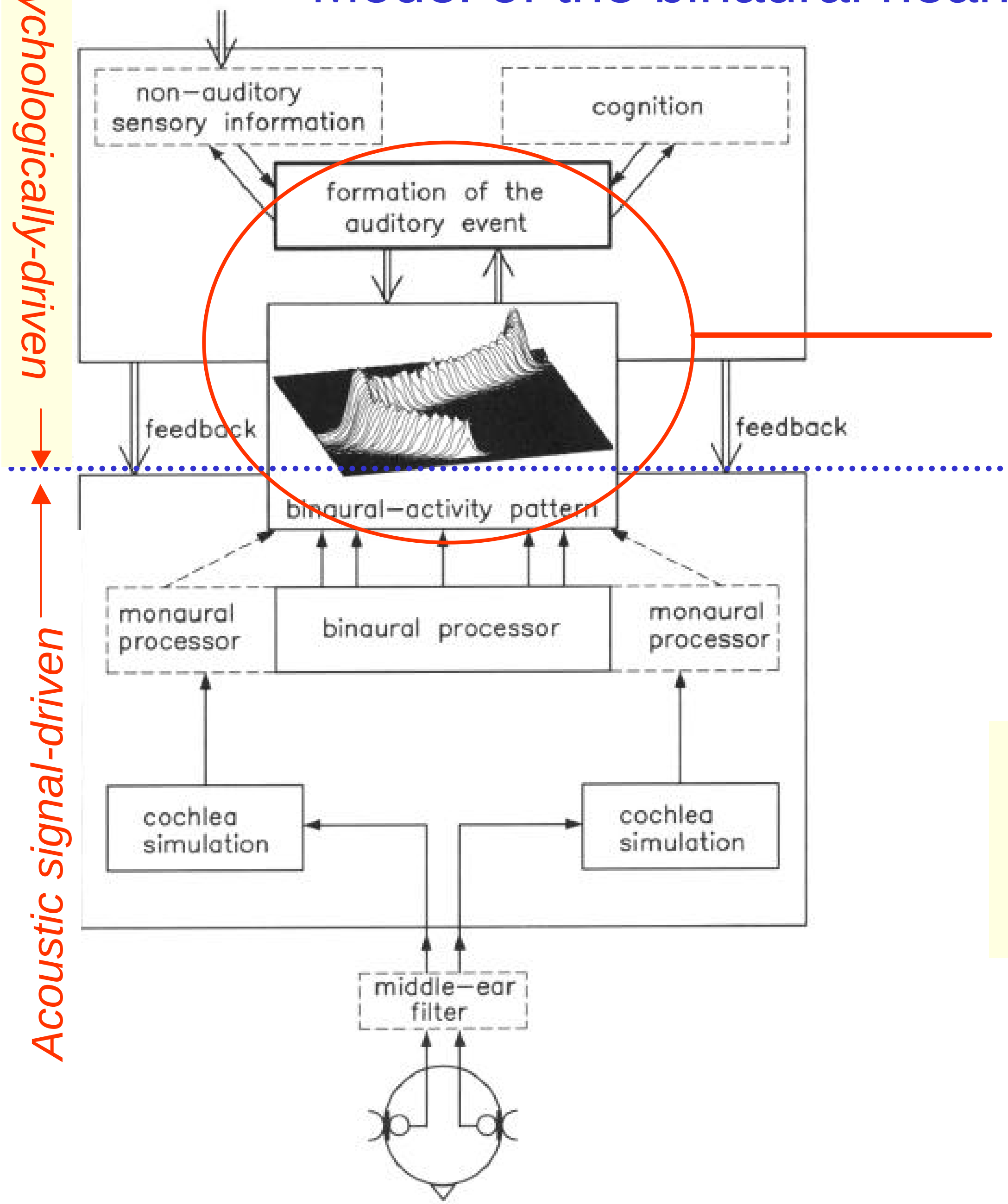
- Localization

    (lateral and 3-dimensional)

- Binaural release from masking:

    Echo supression, room perception

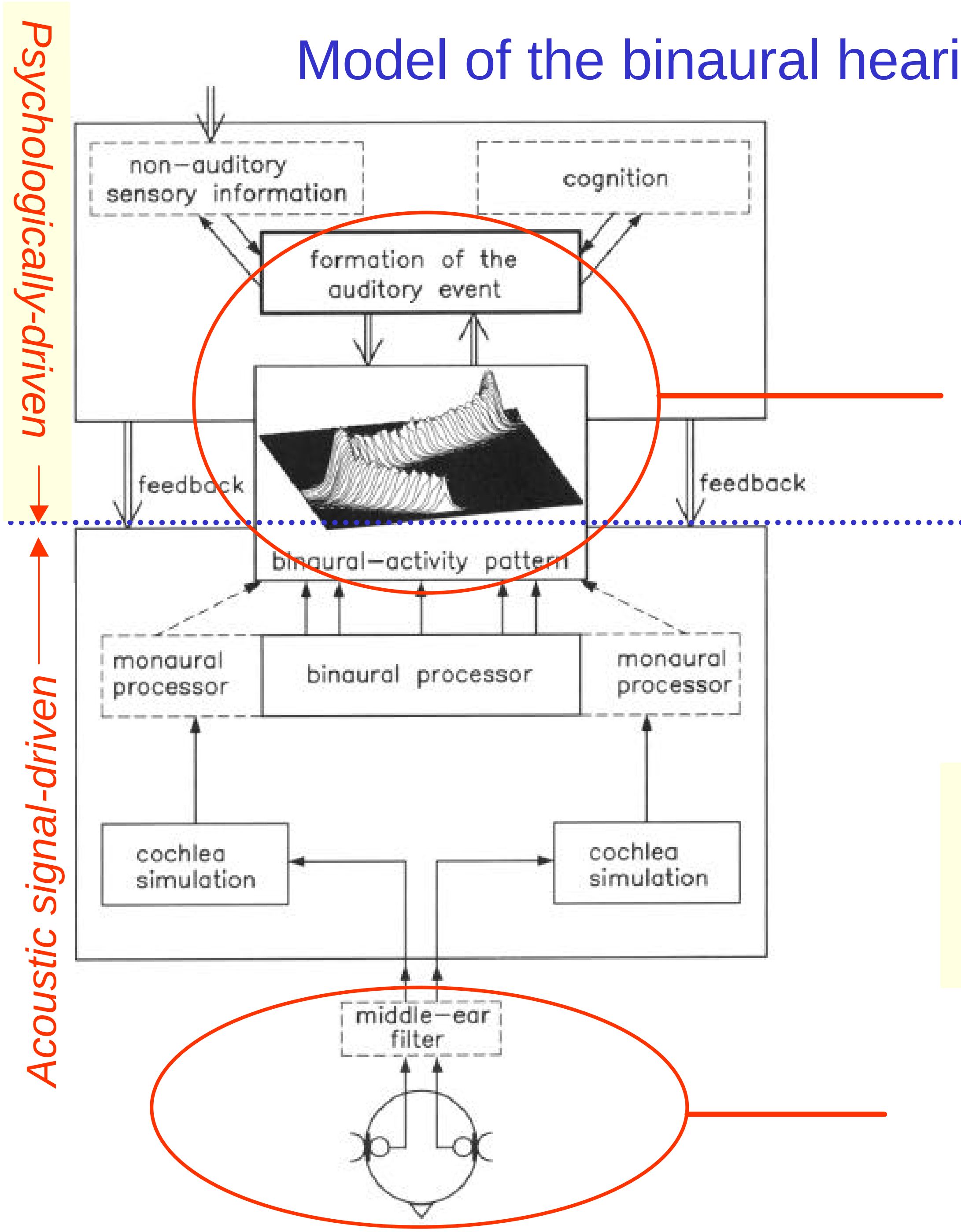
Model of the binaural hearing system



Binaural hearing (localization; signal separation & detection):

forming spatial auditory events from acoustical (bottom-up) and psychological (top-down) inputs

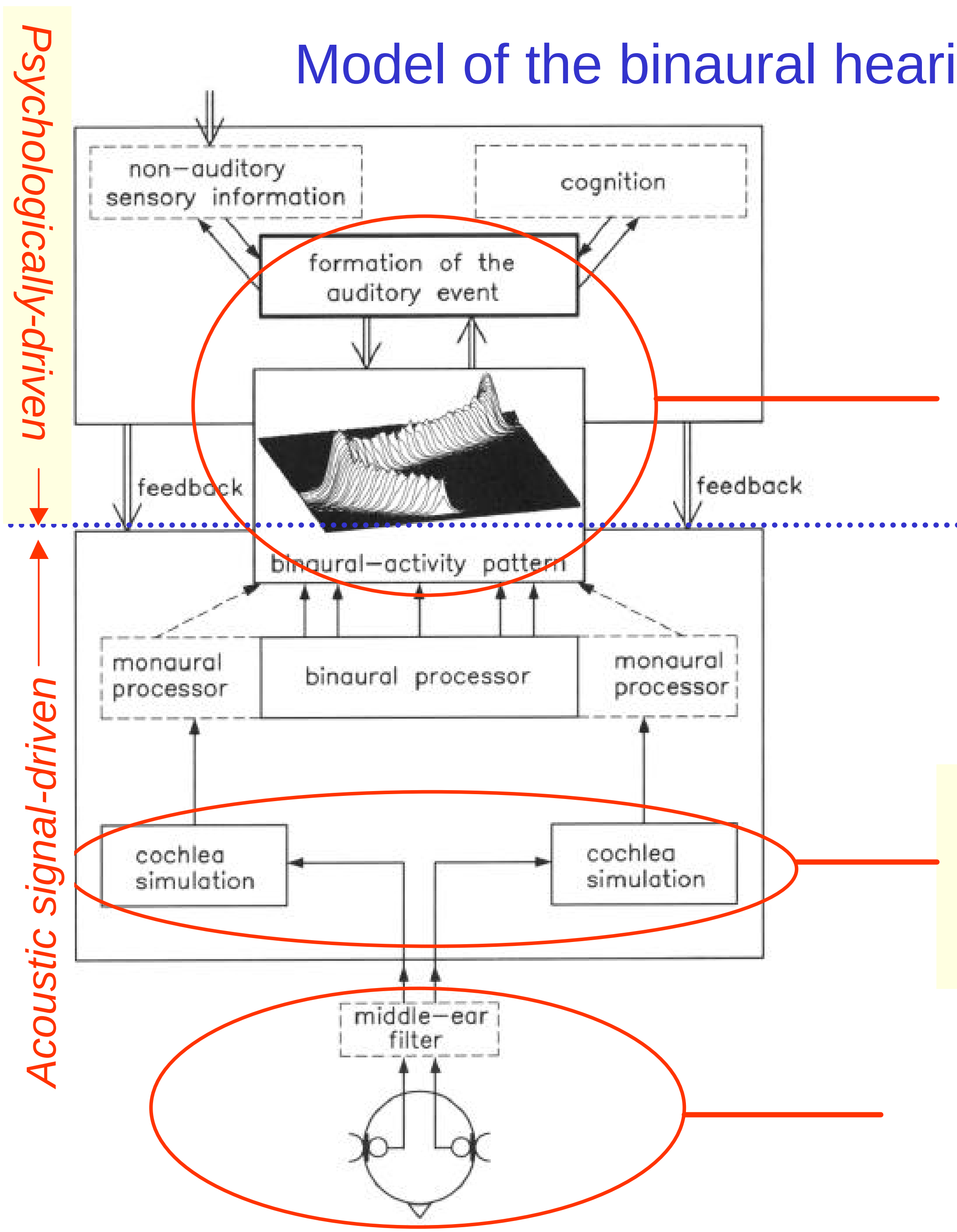
Model of the binaural hearing system



Binaural hearing (localization; signal separation & detection)

Filtering of acoustic signal by pinnae, ear canal

Model of the binaural hearing system

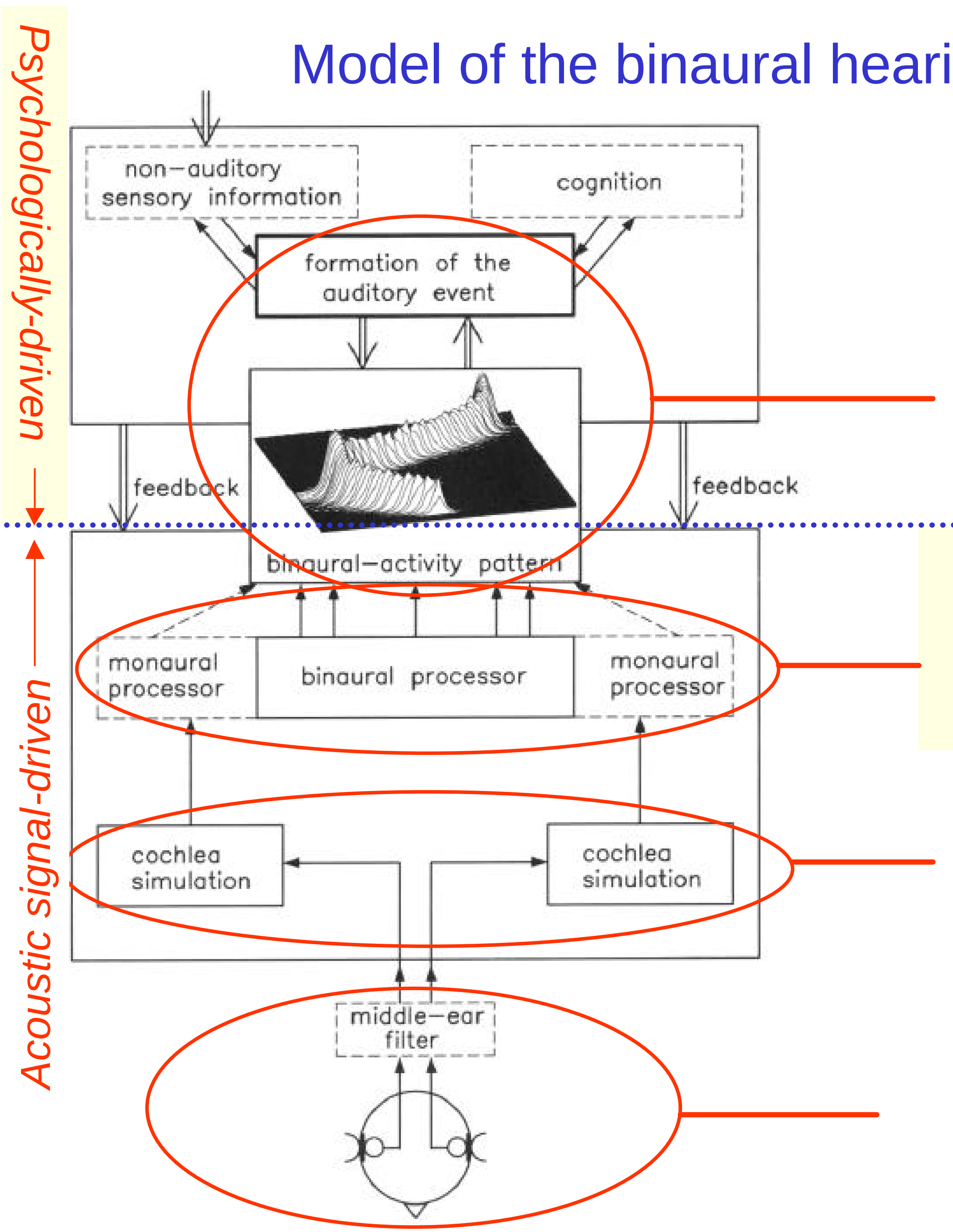


Binaural hearing (localization; signal separation & detection)

Filtering by inner ear; frequency-specific neuron firings

Filtering of acoustic signal by pinnae, ear canal

Model of the binaural hearing system



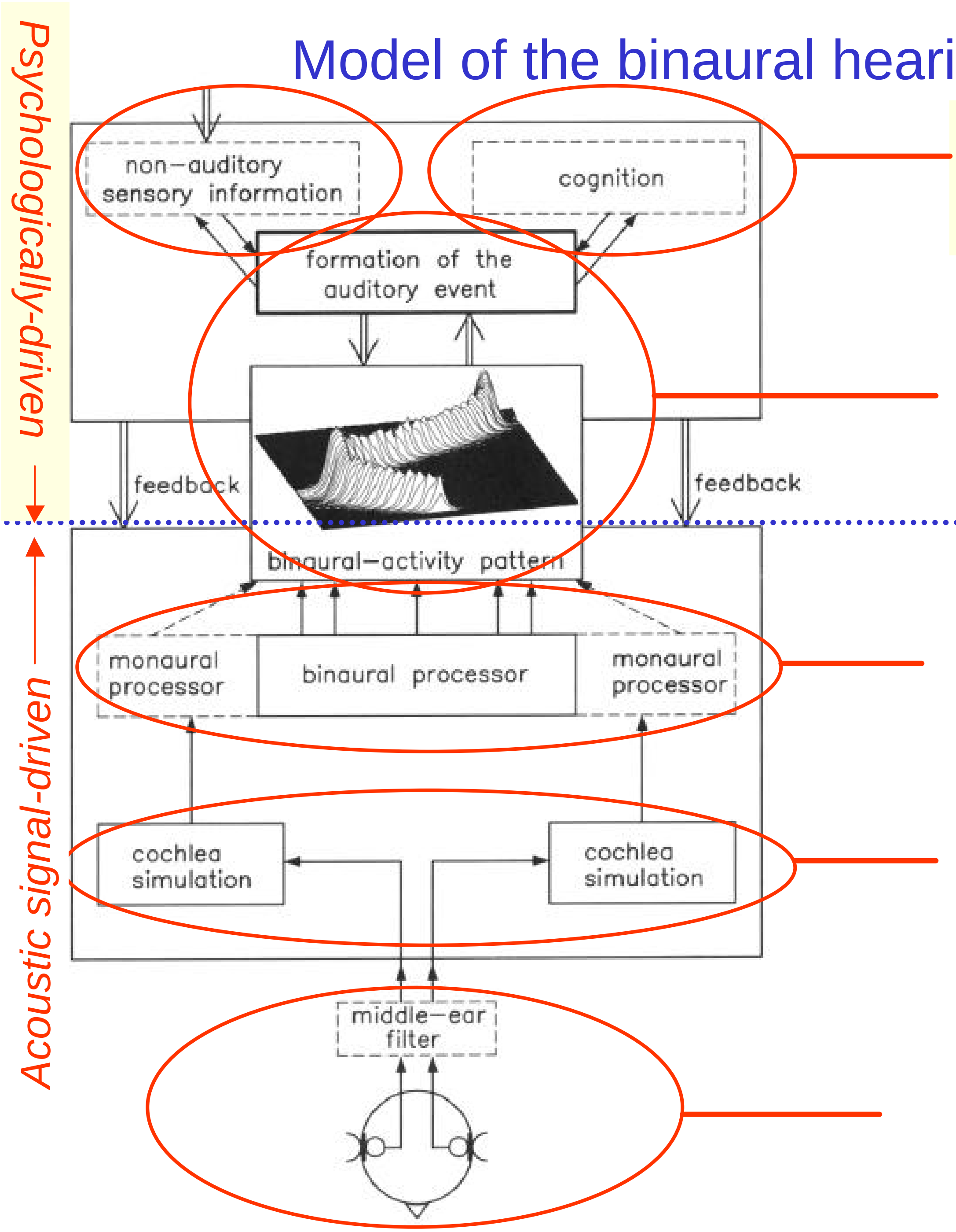
Binaural hearing (localization; signal separation & detection)

Physiological evaluation of interaural timing and level differences

Filtering by inner ear; frequency-specific neuron firings

Filtering of acoustic signal by pinnae, ear canal

Model of the binaural hearing system



Multi-sensory information; cognition

Binaural hearing (localization; signal separation & detection)

Physiological evaluation of interaural timing and level differences

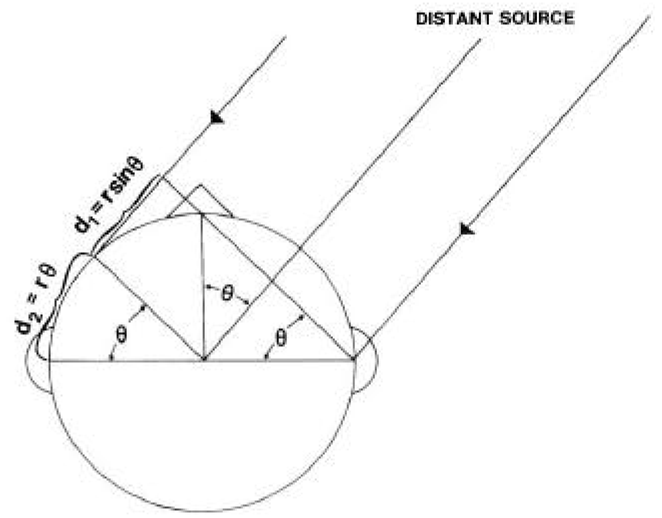
Filtering by inner ear; frequency-specific neuron firings

Filtering of acoustic signal by pinnae, ear canal.

Lateral localization of auditory images

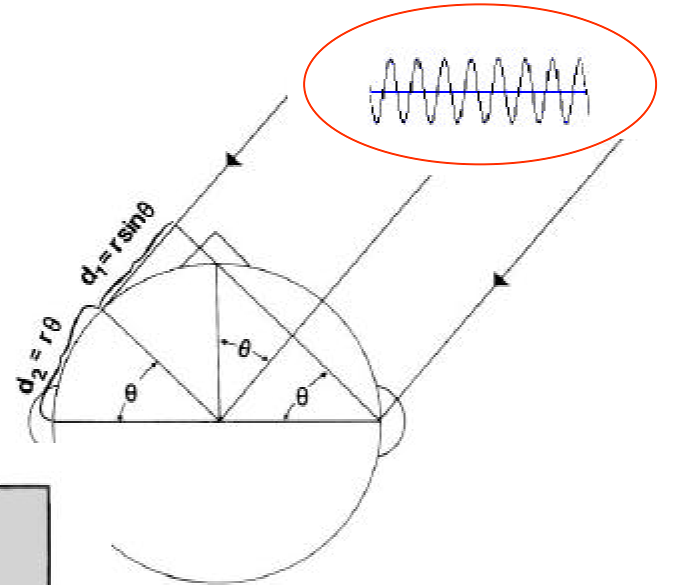
“Duplex” theory of localization

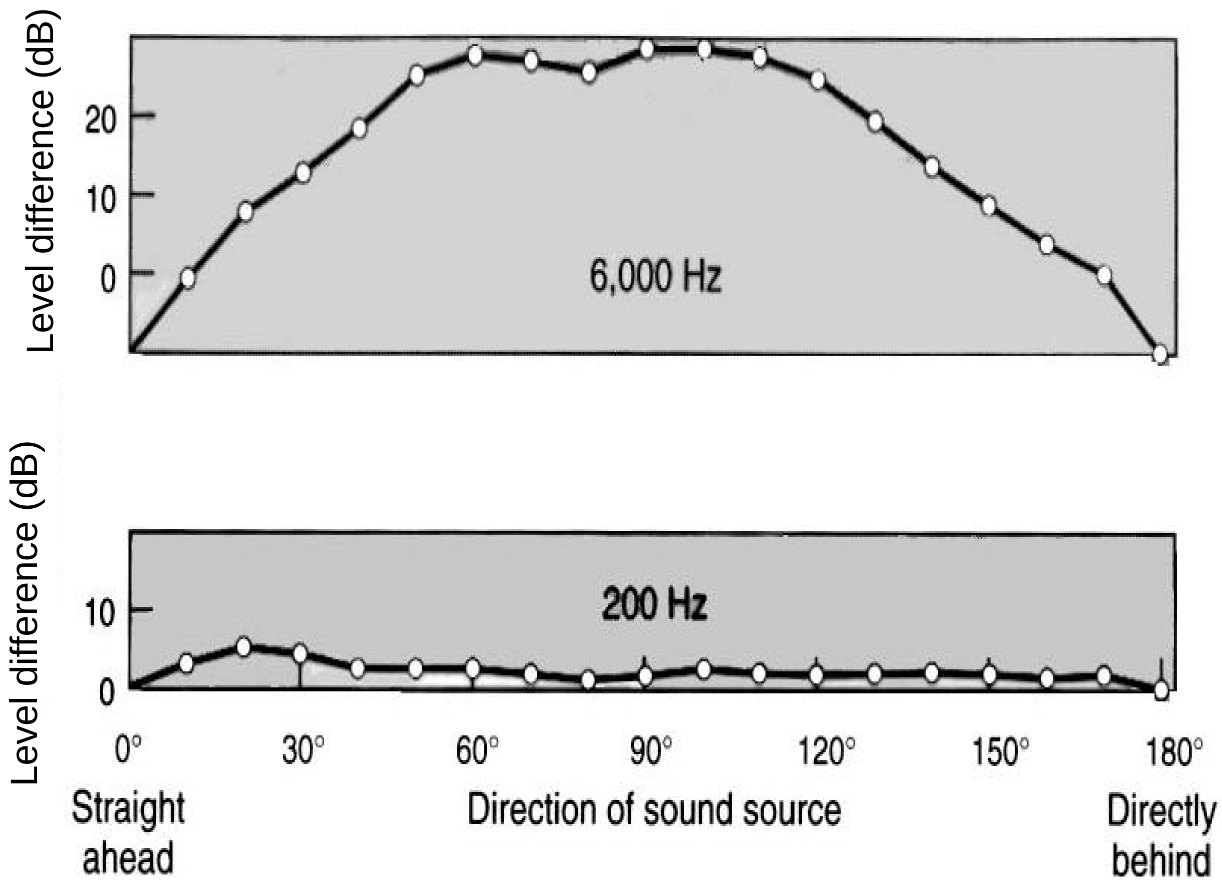
- ILD (interaural level difference)
- ITD (interaural time difference)



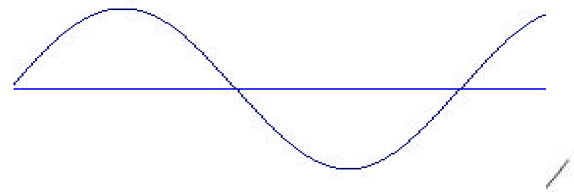
Lateral spatial image shift

- ILD (interaural level difference) caused by head shadow of wavelengths > 1.5 kHz

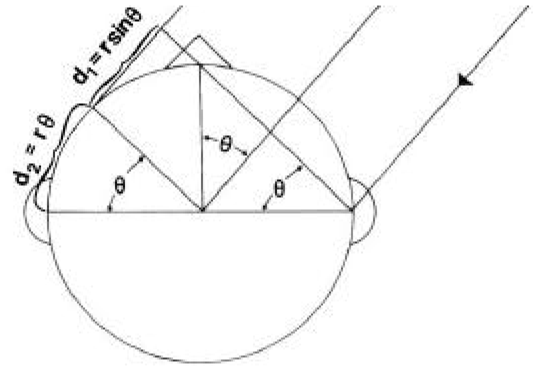


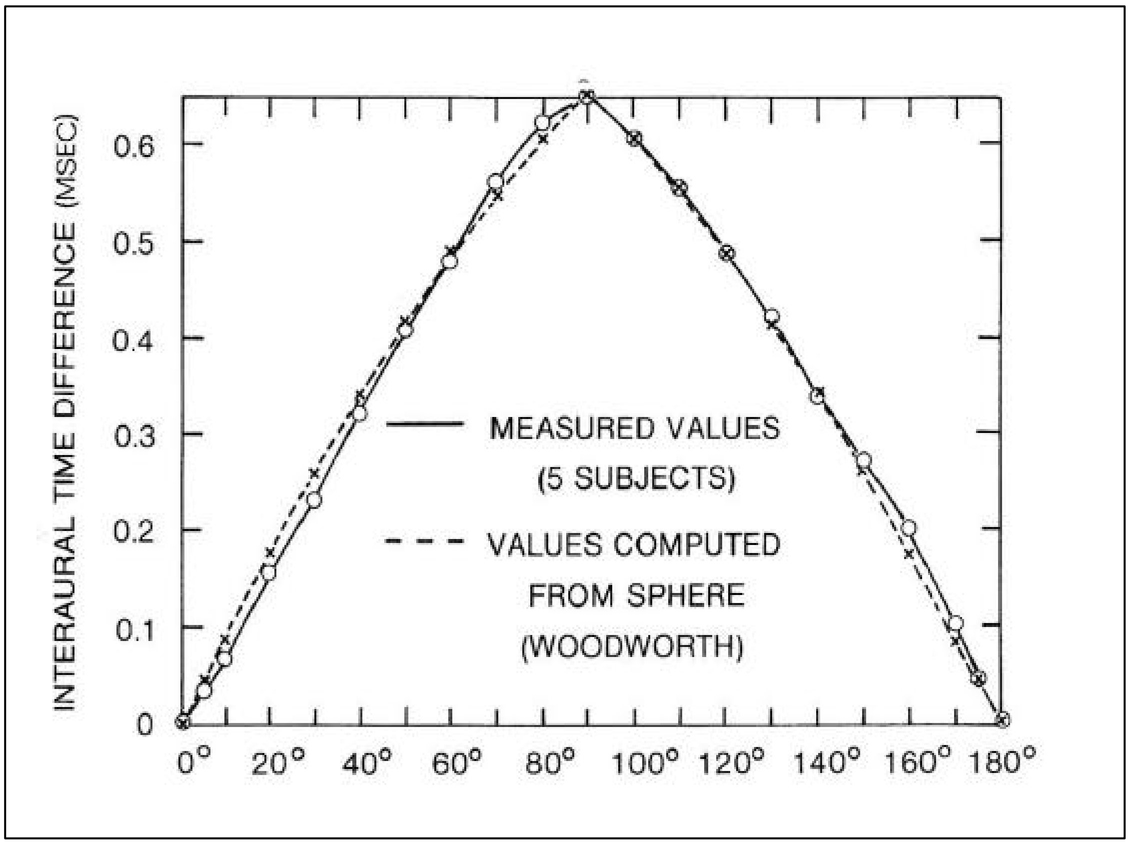


Lateral image shift

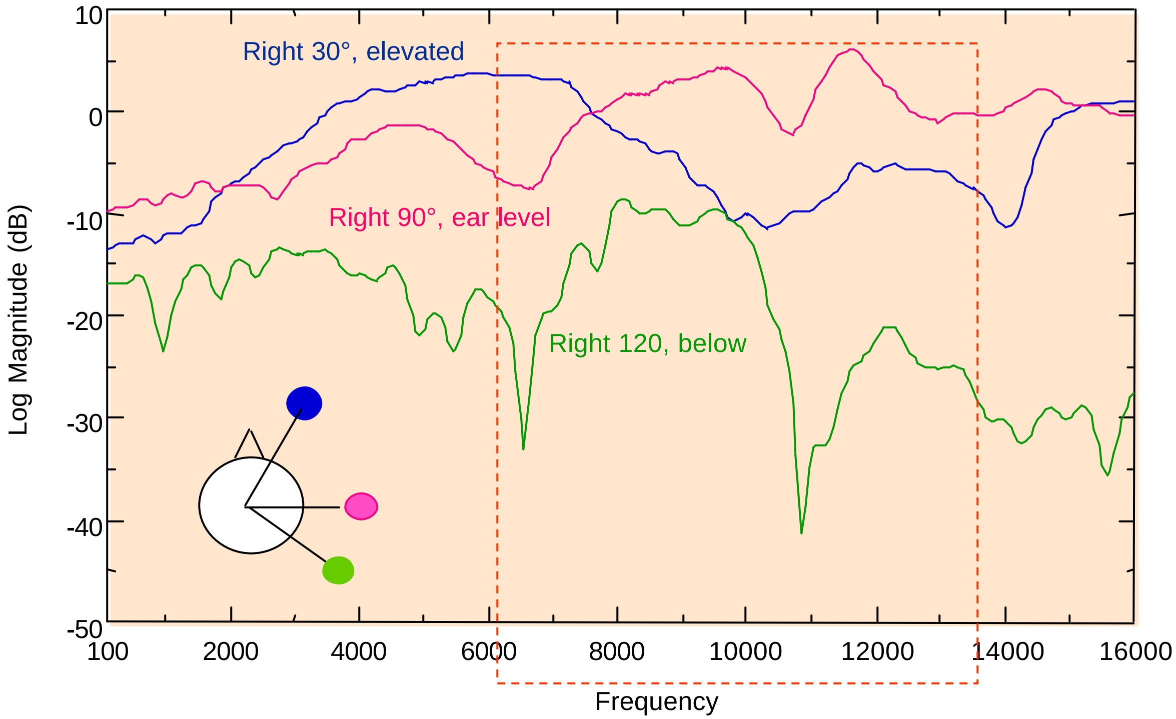


- ITD (interaural time difference)

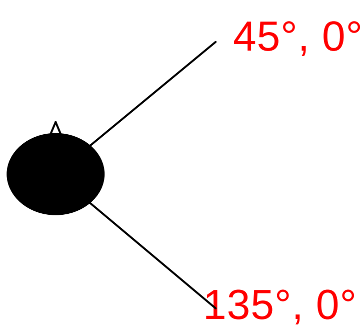


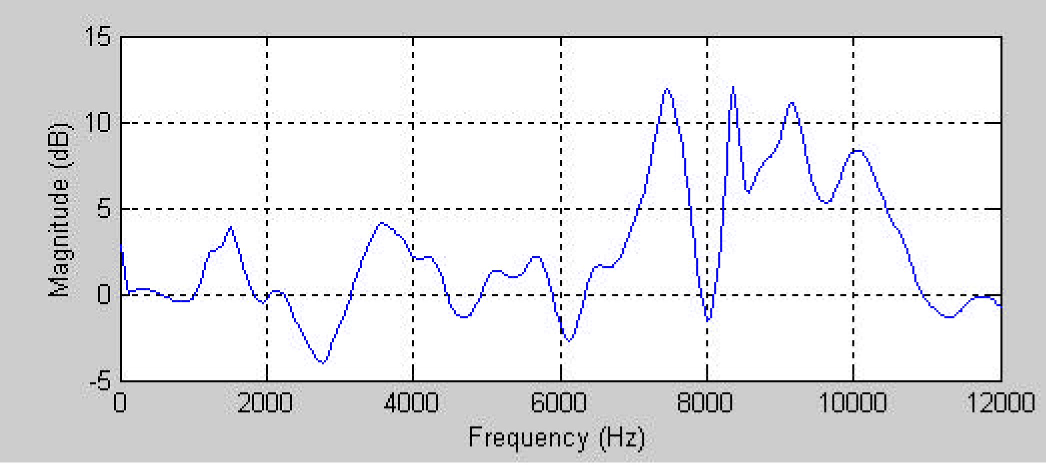


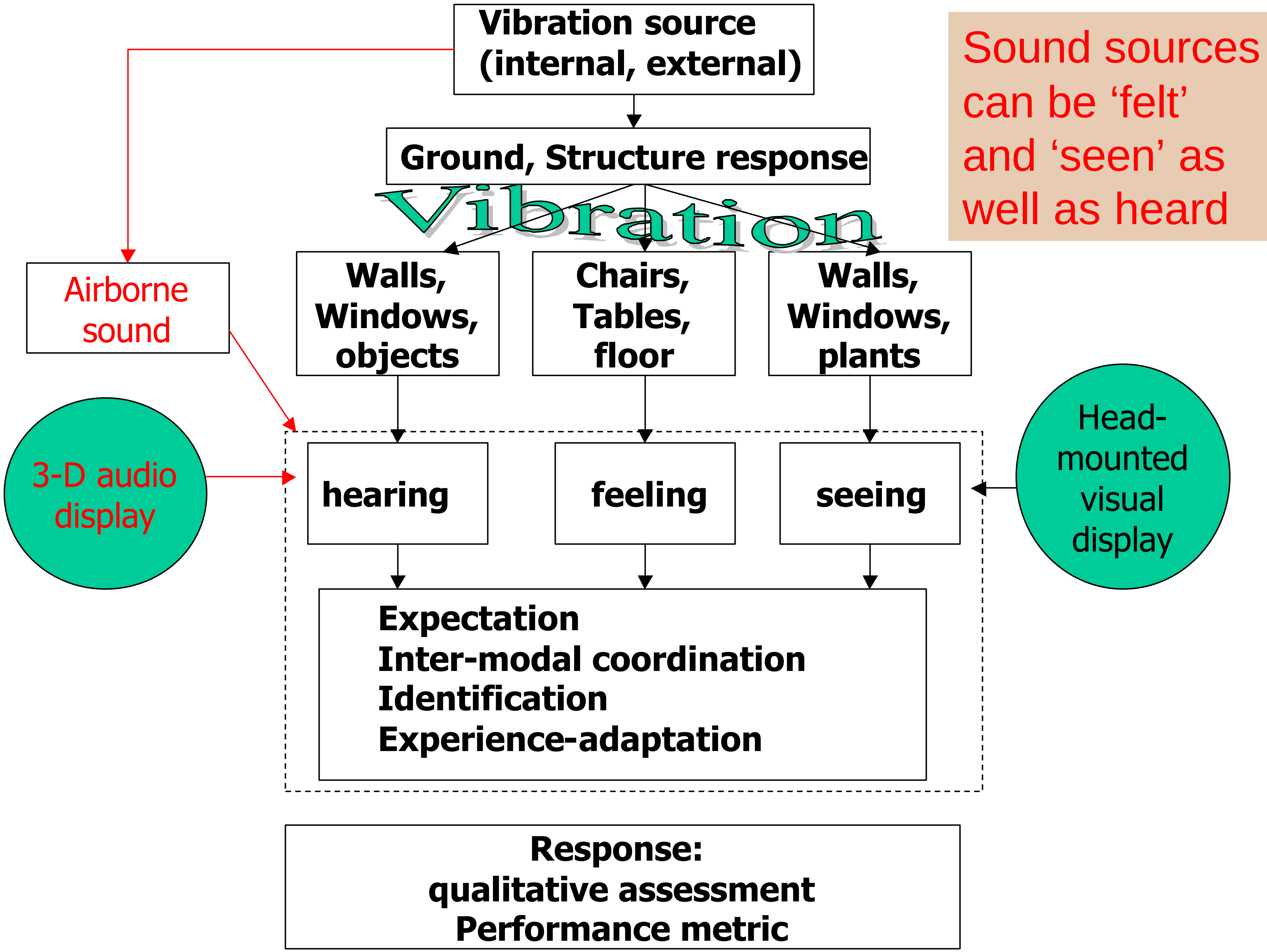
Head-related transfer function cues (HRTFs) provide cues for front-back discrimination and elevation



Basis of 3-D audio signal processing in auditory displays





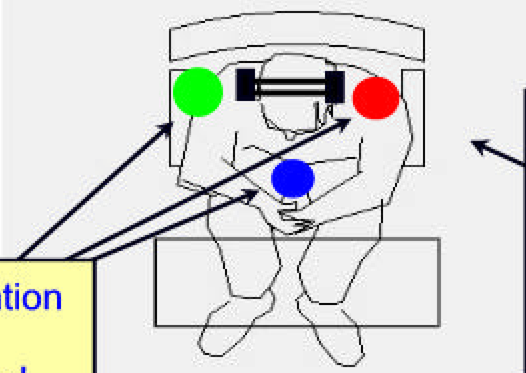


Vibration source
(internal, external)
Ground, Structure response
Vibration
Airborne
sound
Walls,
Windows,
objects
Chairs,
Tables,
floor
Walls,
Windows,
plants
3-D audio
display
hearing
feeling
seeing
Head-
mounted
visual
display
Expectation
Inter-modal coordination
Identification
Experience-adaptation
Response:
qualitative assessment
Performance metric
Sound sources
can be ‘felt’
and ‘seen’ as
well as heard

Applications of spatial sound for improving intelligibility in auditory displays

Using binaural hearing advantage for separating multiple auditory "streams" (simultaneous sources)

Proposed 3-D audio communication system



Each communication channel is spatially separated.

User can use selective attention to switch between signals, as in normal hearing.

Background noise reduced via on-the-ear, active noise cancellation headsets.

Normal communication still possible without intercom

* Improved intelligibility

* Less fatigue

3-D communication system patented, developed for NASA-KSC

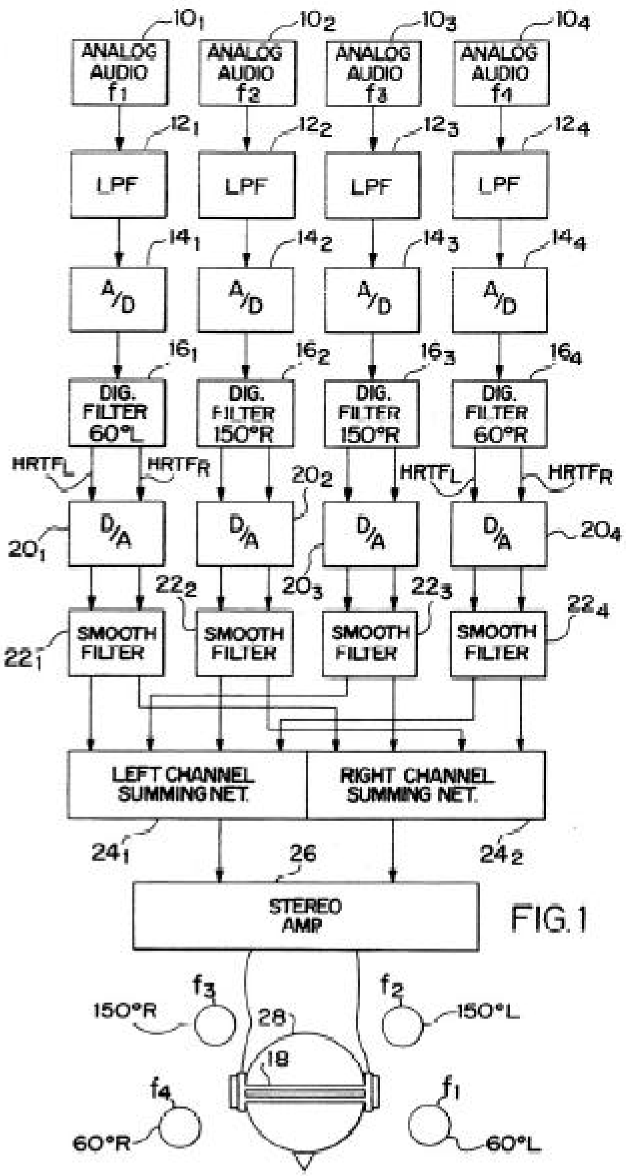


FIG.1

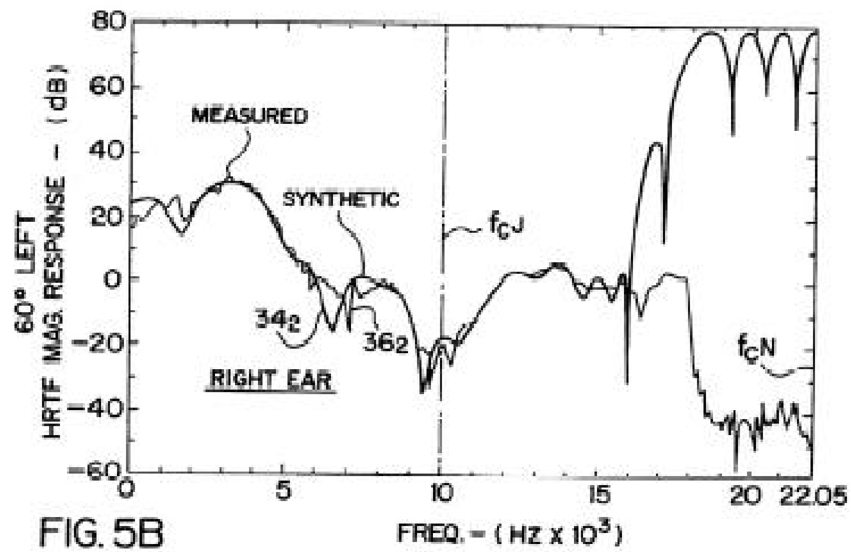
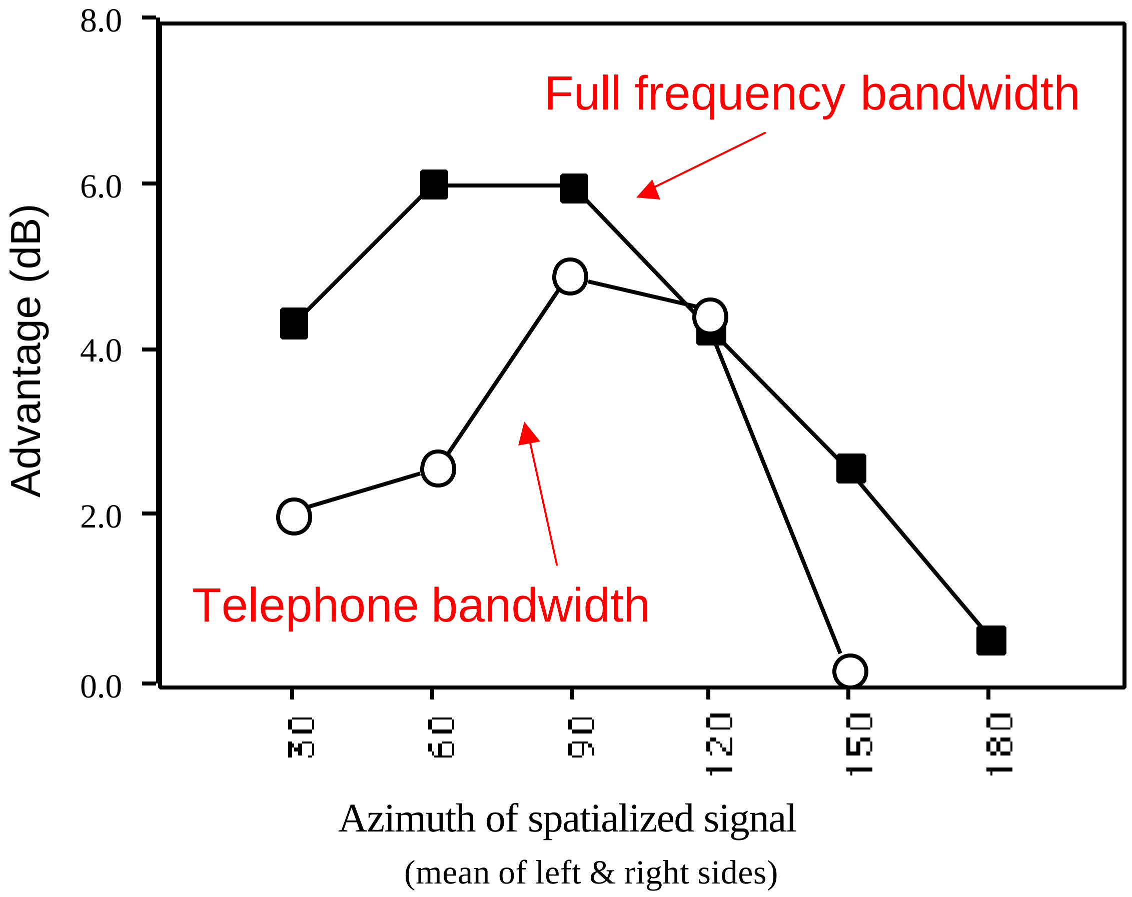
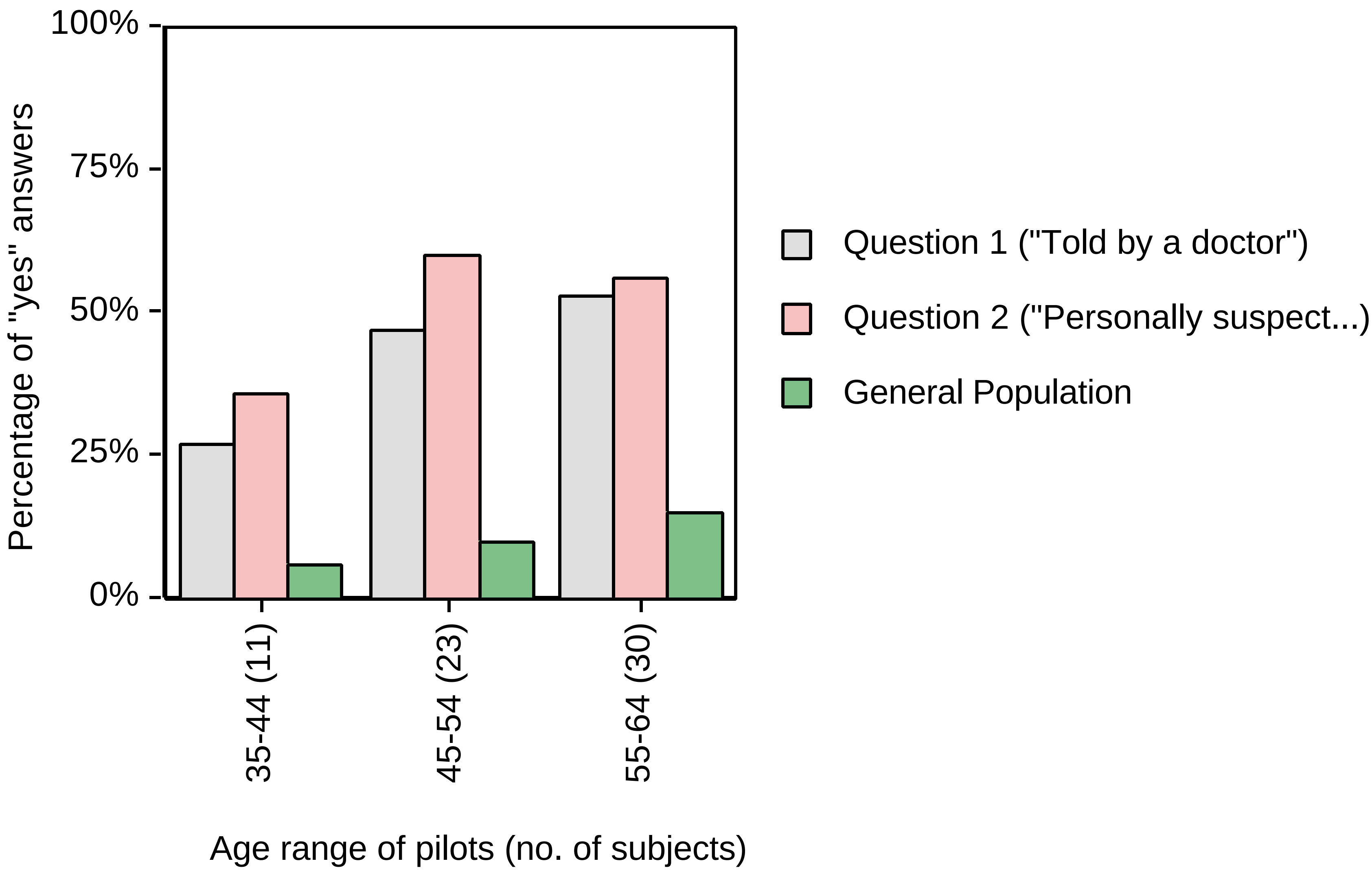


FIG. 5B

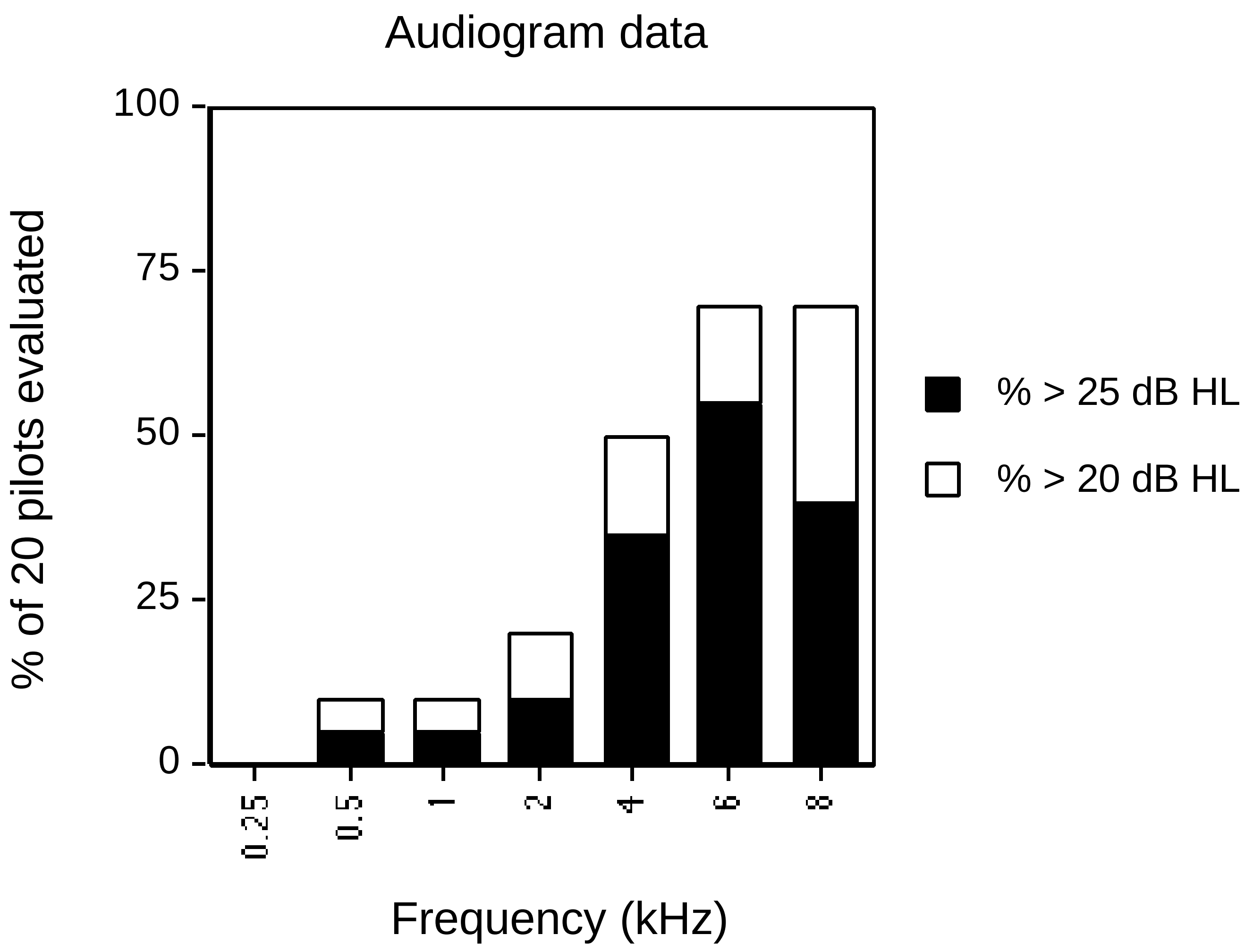
Speech Intelligibility advantage compared to one-ear listening



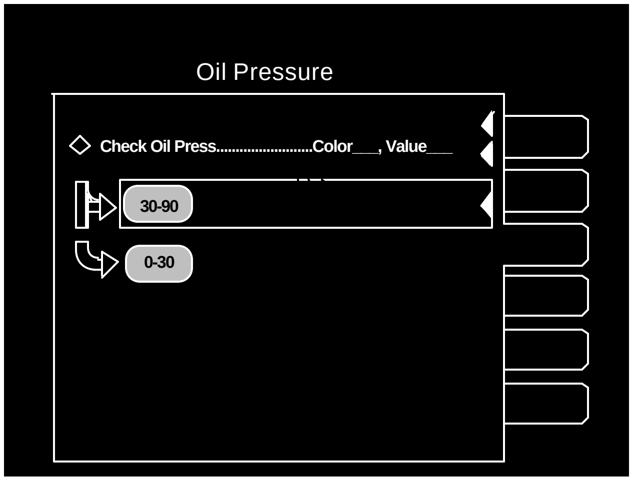
Hearing loss for target users: 64 active commercial airline pilots



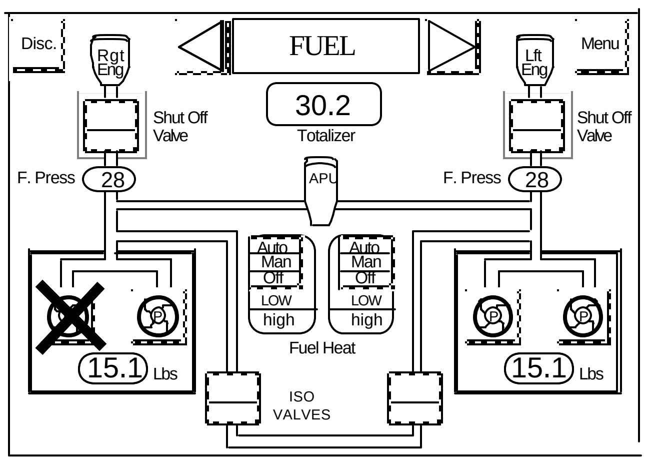
Audiogram data summary for 20 active commercial pilots (age range 35-64; not corrected for presbycusis)



Use of auditory icons (AI) and left-right spatialization for information redundancy, situational awareness of actions of crew (CRM) and haptic feedback substitution



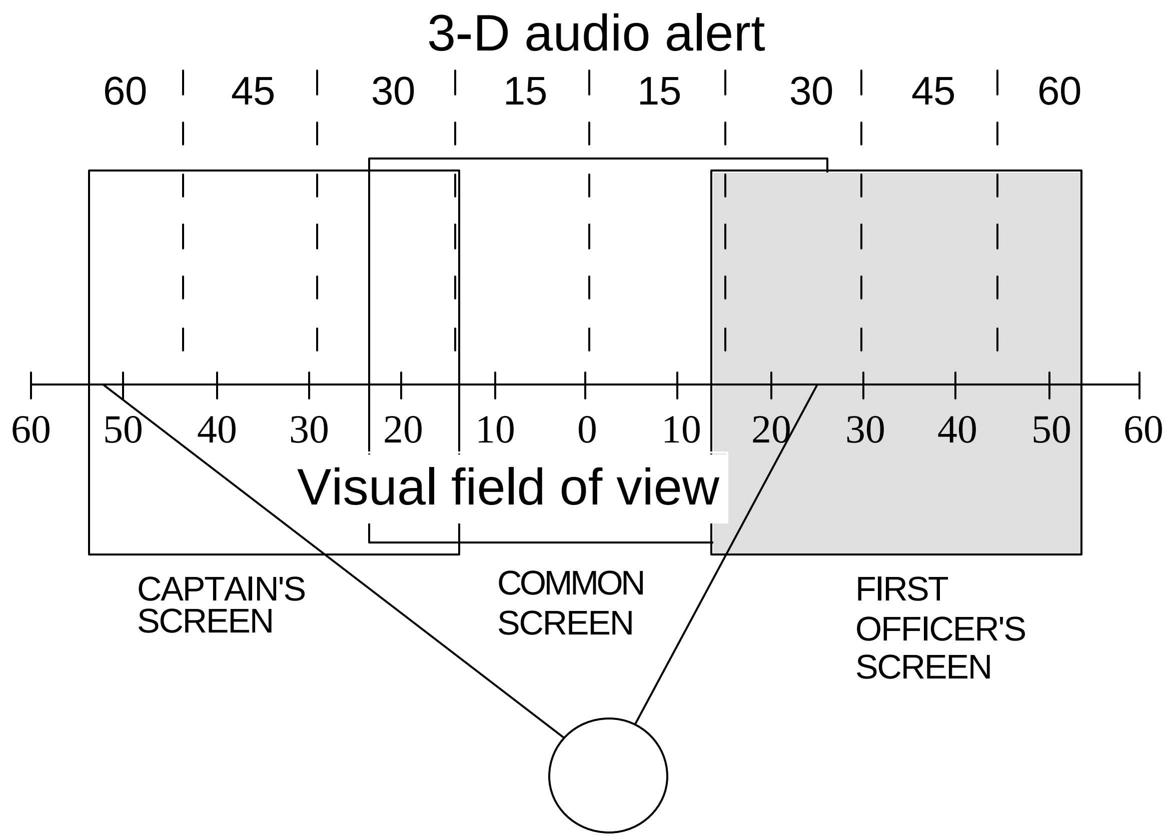
"Page-through" & "switch" AIs for touch screen checklist



"Mechanical latch" AIs for actions corresponding to electrical, fuel, hydraulic systems

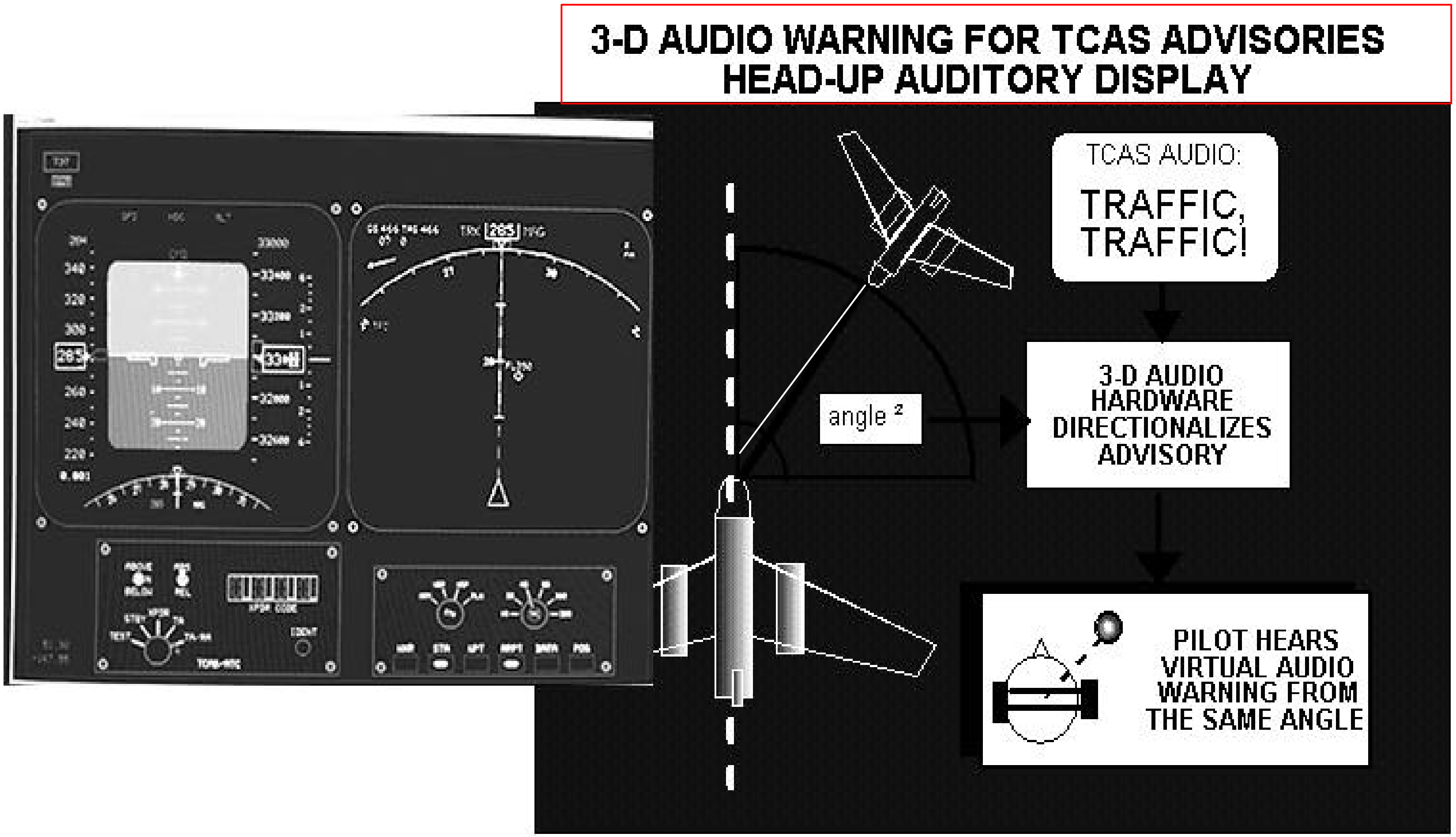
NASA ARC advanced cab simulator

Head up auditory display for TCAS

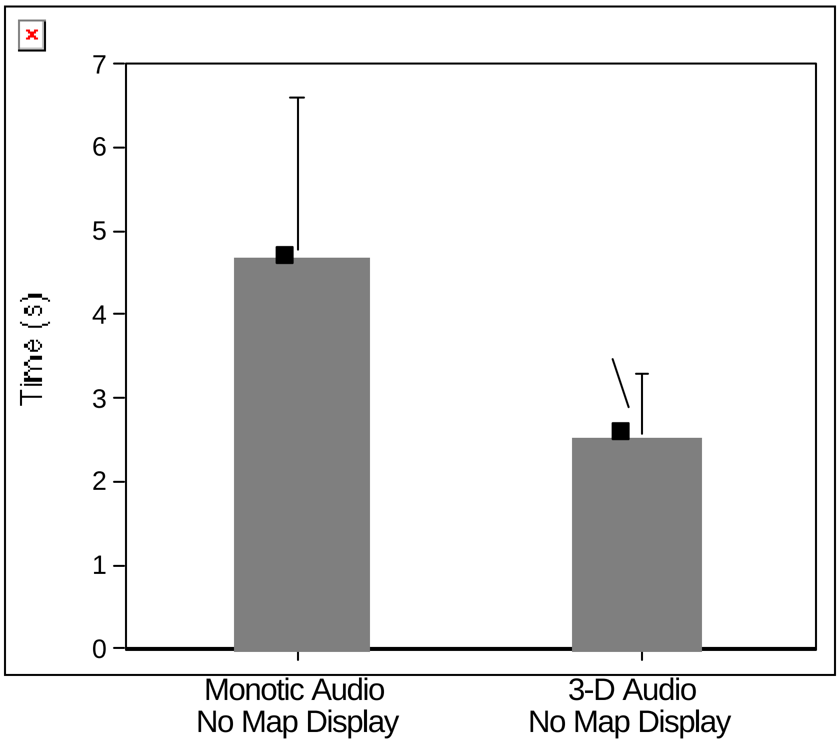


Application of 3-D audio head-up display for Traffic Collision Avoidance System (TCAS II) investigated.

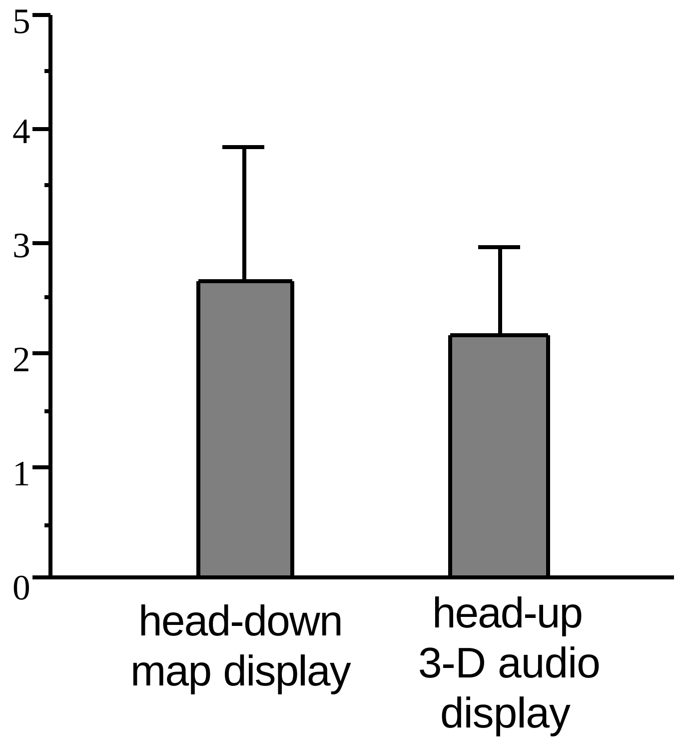
Target acquisition times can decrease from 0.5 – 2.2 sec.



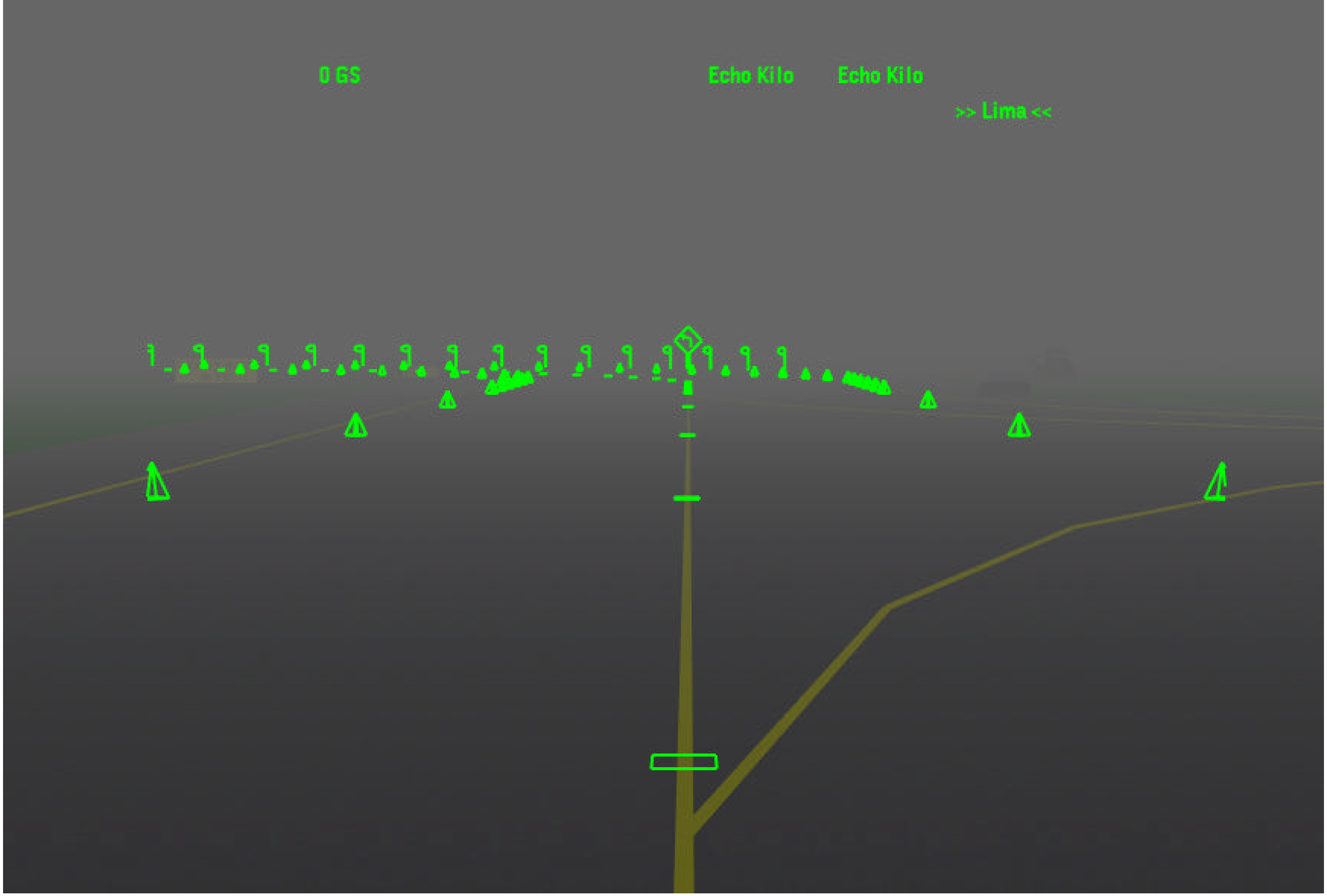
Mean target acquisition times (4.7 vs. 2.5 s) and standard deviations for first TCAS experiment. The 3-D audio cues were exaggerated in azimuth relative to the visual target, and no elevation cues were supplied.

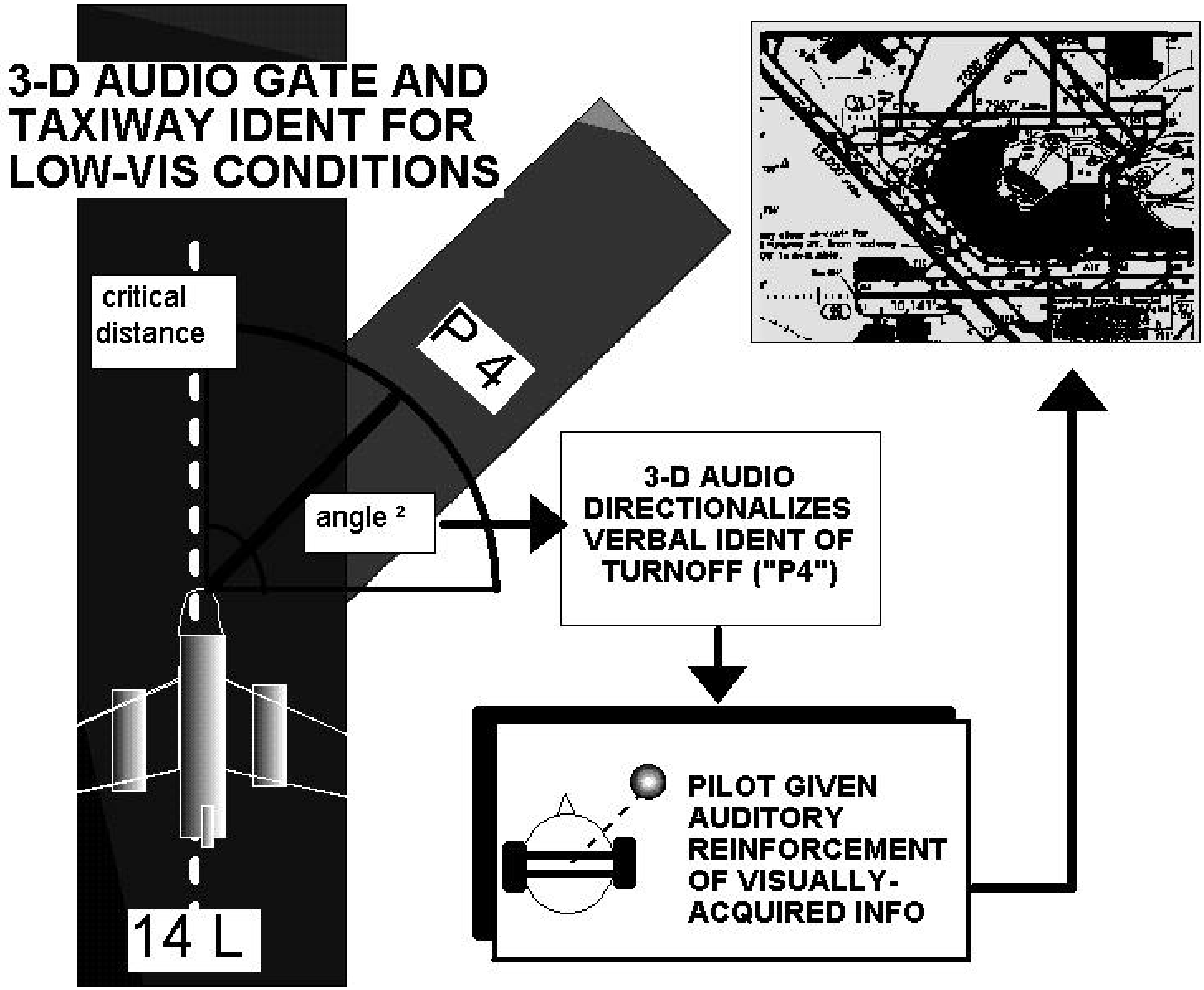


Mean target acquisition times (2.63 vs. 2.13 s) and standard deviations for second TCAS experiment. The 3-D audio cues were not exaggerated, and there were three categories of elevation cues.



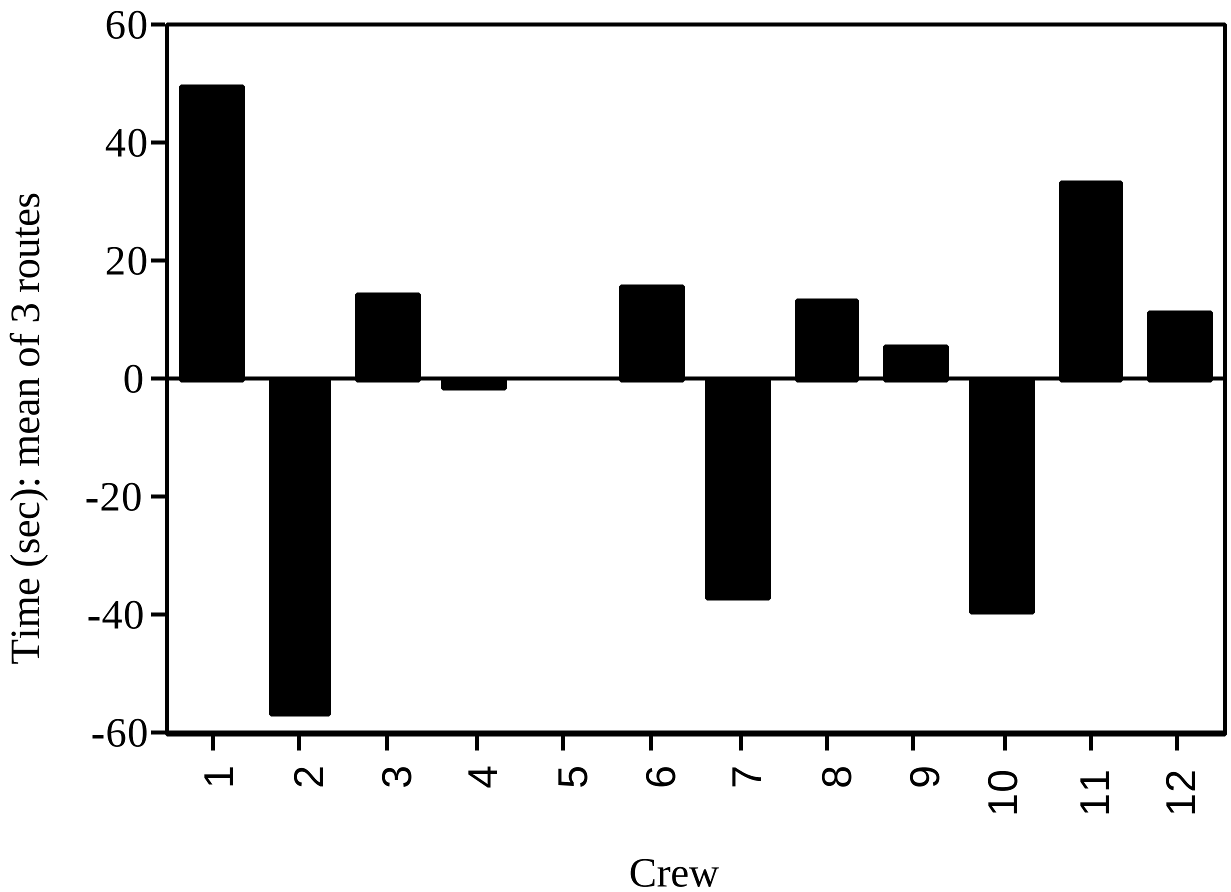
Head-up auditory display with head-up visual display





Application of 3-D audio head-up display for taxiway turnoff guidance

Reduction in taxi time:
Advantage of 3-D audio



Spatially-modulated auditory alerts

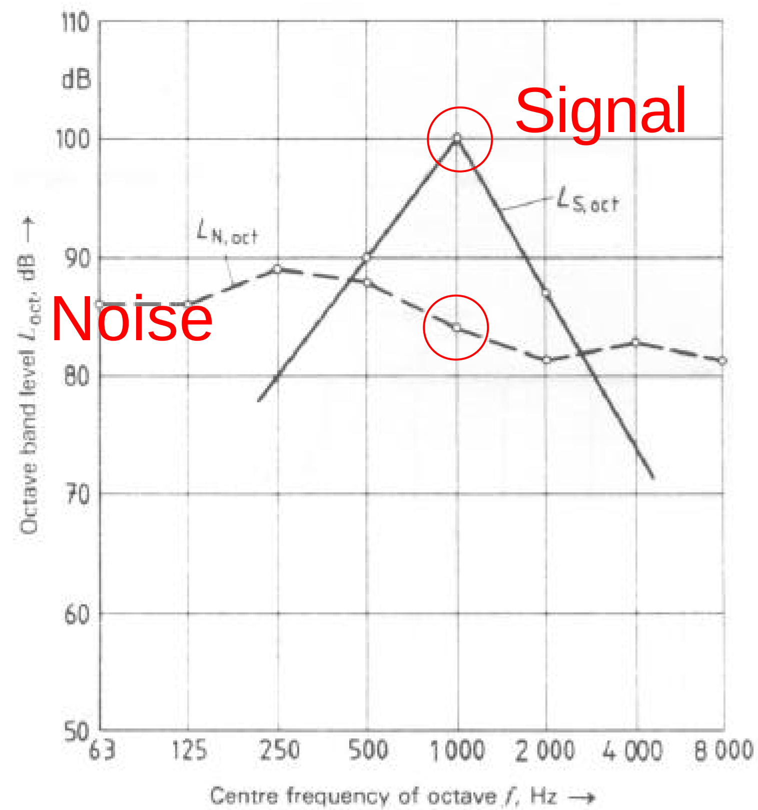
In an auditory display, how to insure that an alarm is audible?

-“Common sense” engineering approach: make the alarm *a lot louder* than the background noise for wide-area coverage

Fire alarm and horn from ca. 1933

In an auditory display, how to insure that an alarm is audible?

-ISO 7731 (“Danger signals for work places-Auditory danger signals”) specifies signal to be >= 13 dB re masked threshold in a 1/3 octave band (0.3-3.0 kHz)



-Recipe for “startle effect”, high overall SPLs, *and potentially low performance in a high-stress environment*

Current approach

-Improve detection of an alarm (signal) against ambient sound (noise) using signal processing techniques other than level increase

Requirement / Caveat

-Technique should apply to currently-used alarms (to avoid “relearning” semantic content of new auditory signals).

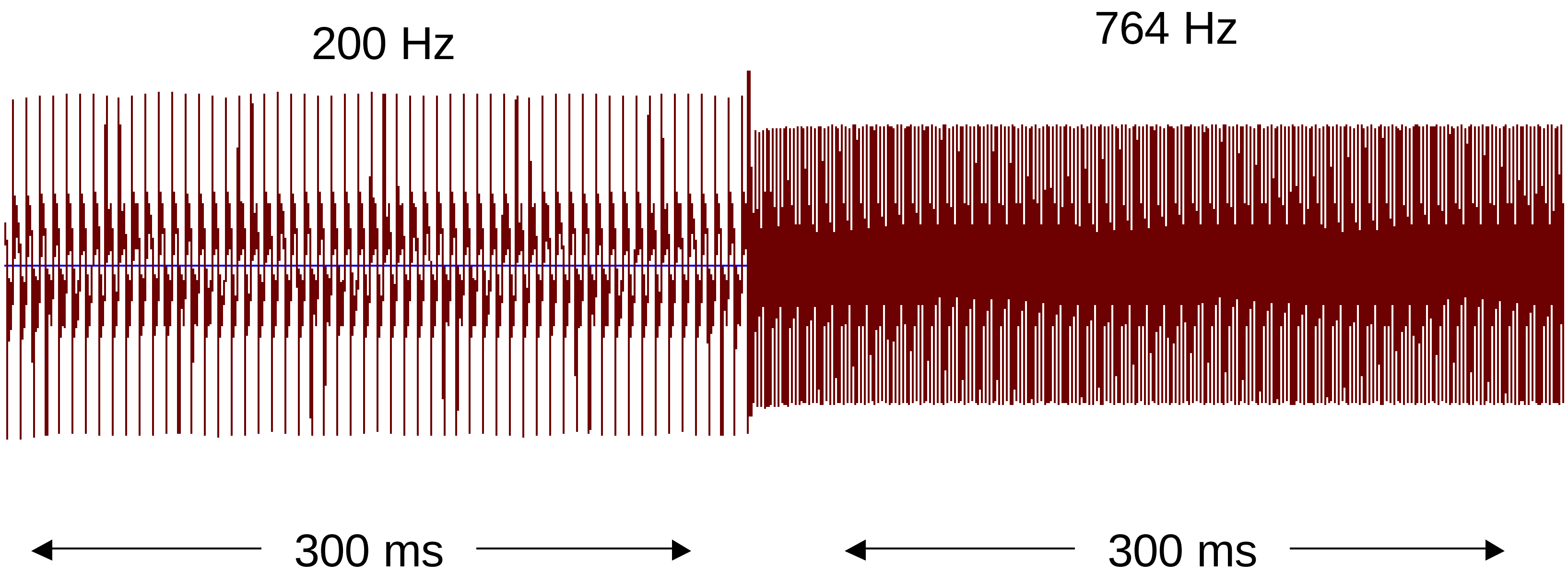
Technique

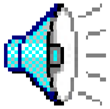
-Three methods addressed in patent application (pending) for accomplishing this.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

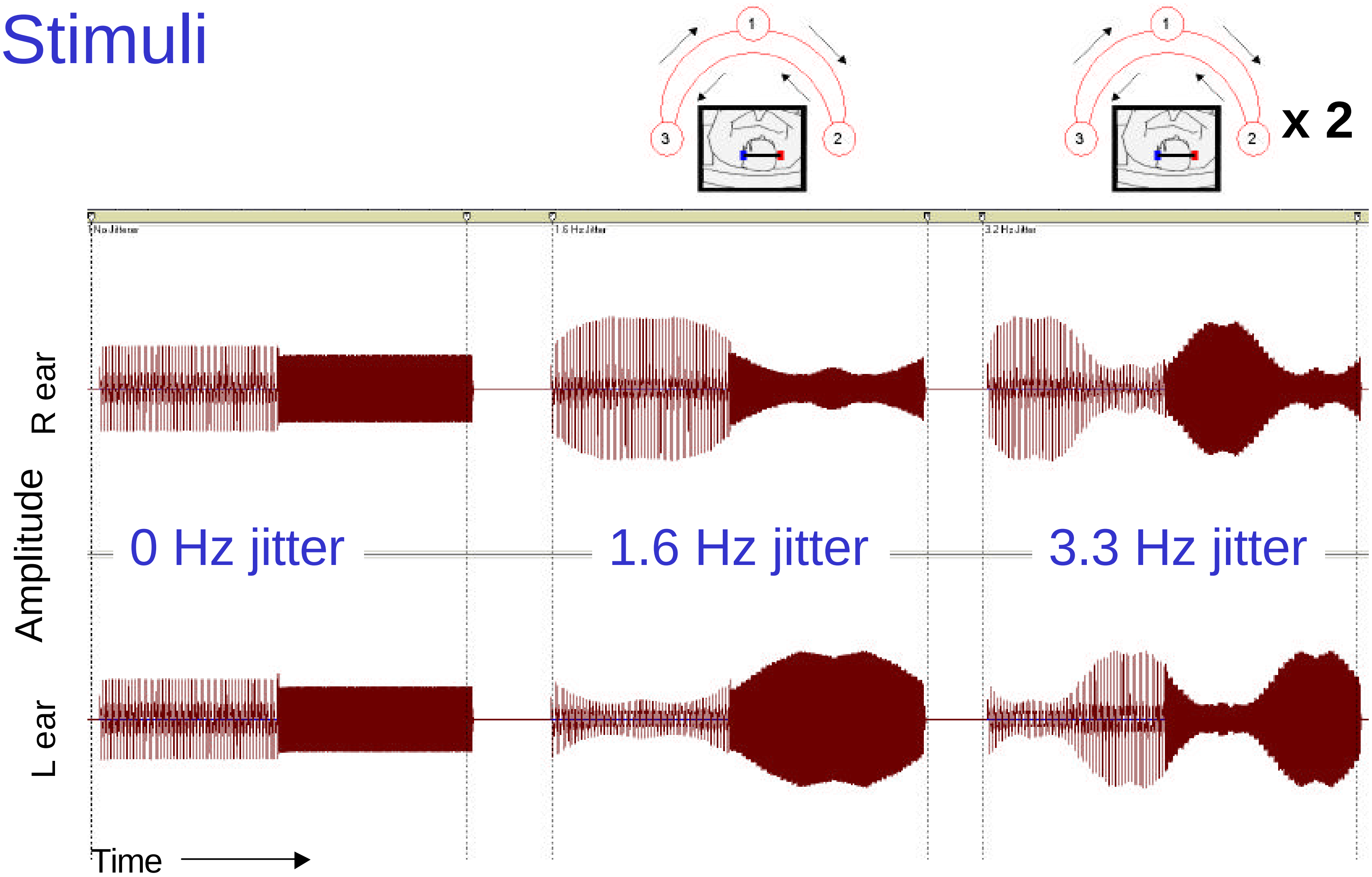
Alarm (basic stimulus)

737-300 alarm: Two successive square waves (preceding verbal “wind sheer” alert)





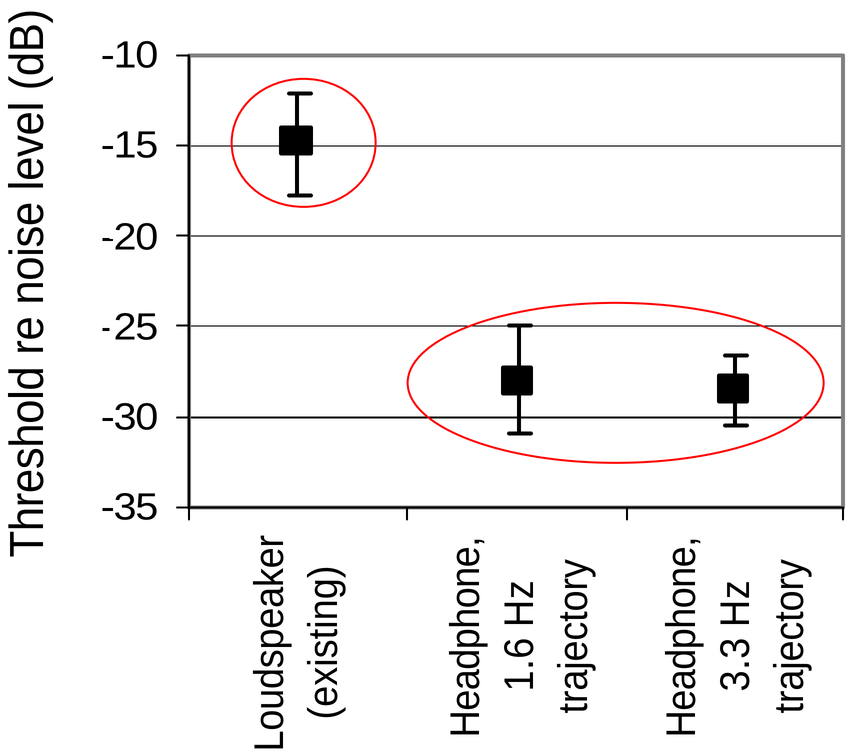
Stimuli



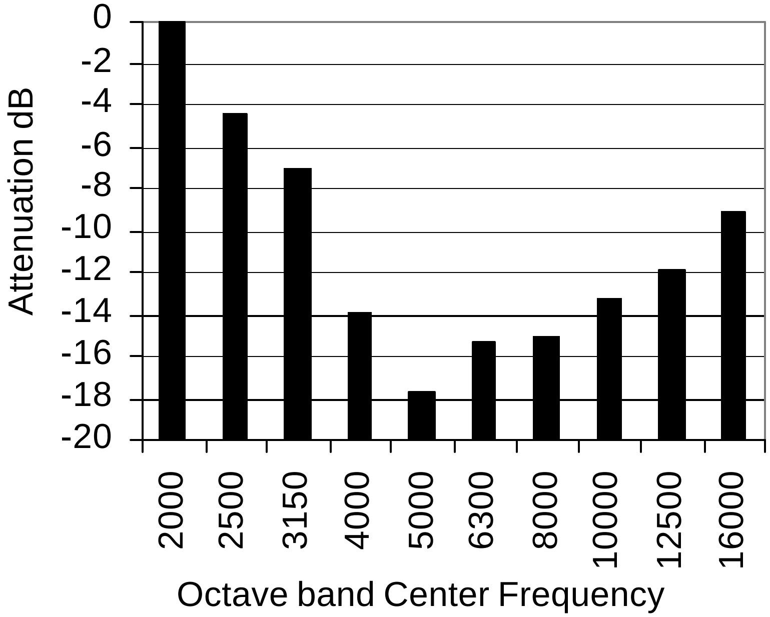
Summed L+R RMS levels equivalent for all stimuli; but jittered stimuli have + 5 dB peaks *re* unjittered due to HRTF.

Results (1)

Headphone with jittered signal has 13.4 dB advantage over monaural loudspeaker (existing condition on aircraft), partly due to attenuation of noise by headphone



Results

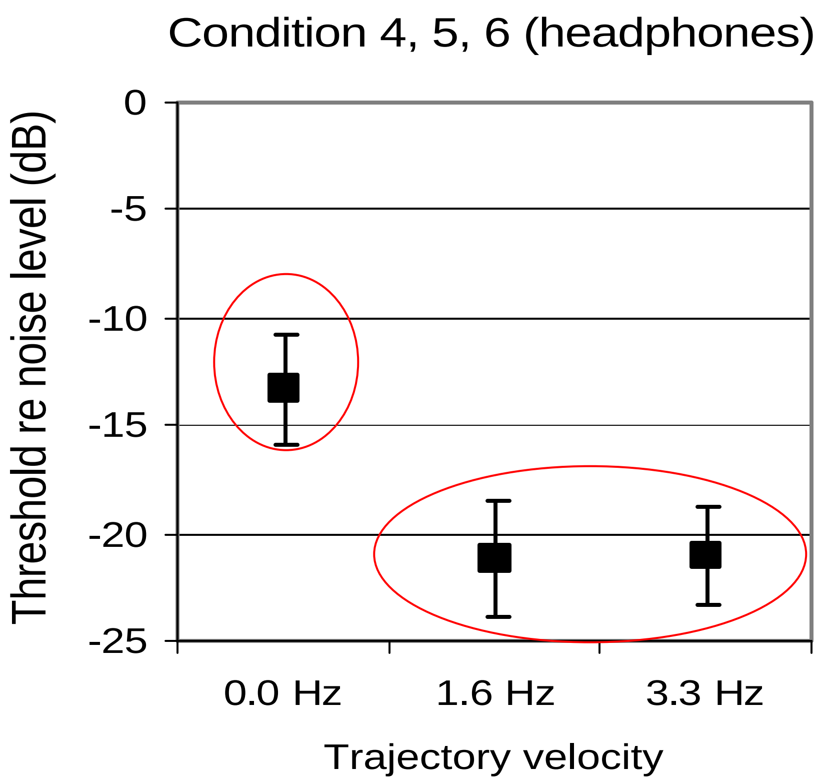


Headphone attenuation

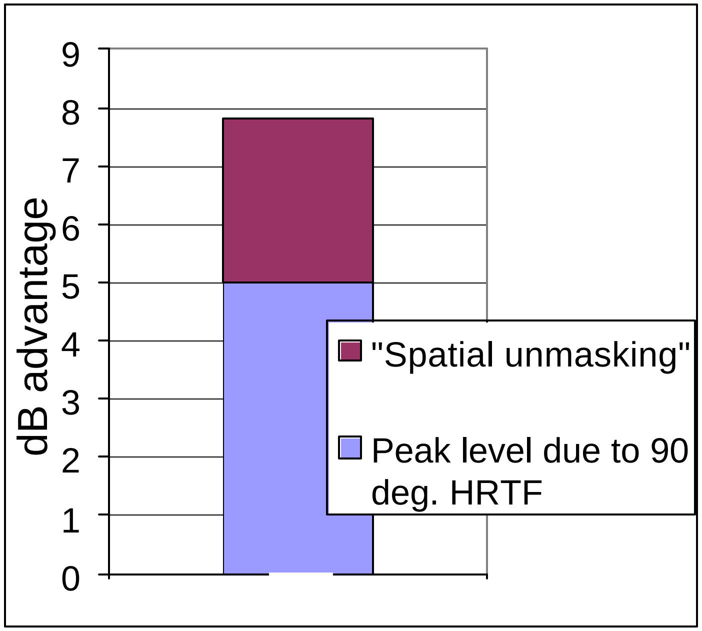
Sennheiser HD 480 vented

Results (2)

Headphone with jittered signal has significant *(p < .000)* 7.8 dB advantage over headphone without jittered signal.
No significant difference between 1.6 and 3.3 Hz modulation.



results



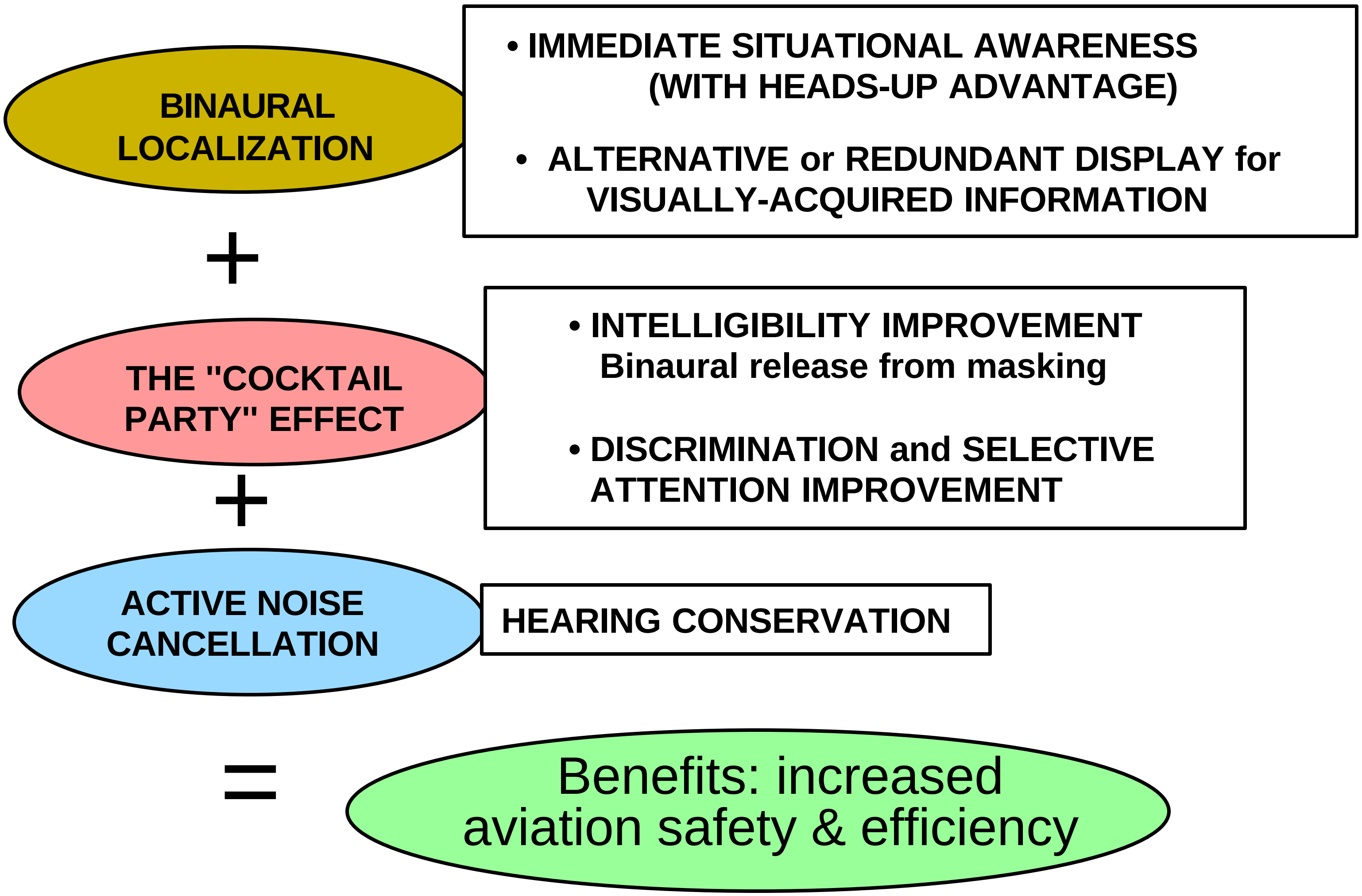
source of unmasking (?)

Conclusions

A new approach to designing alerts for auditory displays in high-stress interfaces: use of spatial modulation for improved detection.

Headphones + spatial modulation lower threshold by 13.4 dB.

Spatial modulation lowers threshold by 7.8 dB.
5 dB is due to HRTF interaural level difference **if** instantaneous (peak) level differences are assumed. This amount is reduced as a function of longer temporal integration periods. Remaining advantage is due to time varying interaural cross-correlation.


BINAURAL LOCALIZATION
• IMMEDIATE SITUATIONAL AWARENESS (WITH HEADS-UP ADVANTAGE)
• ALTERNATIVE or REDUNDANT DISPLAY for VISUALLY-ACQUIRED INFORMATION
+
THE "COCKTAIL PARTY" EFFECT
• INTELLIGIBILITY IMPROVEMENT Binaural release from masking
• DISCRIMINATION and SELECTIVE ATTENTION IMPROVEMENT
+
ACTIVE NOISE CANCELLATION
HEARING CONSERVATION
=
Benefits: increased aviation safety & efficiency