Psychophysical examination of the accuracy and precision of sound localization with respect to sound source diameter.

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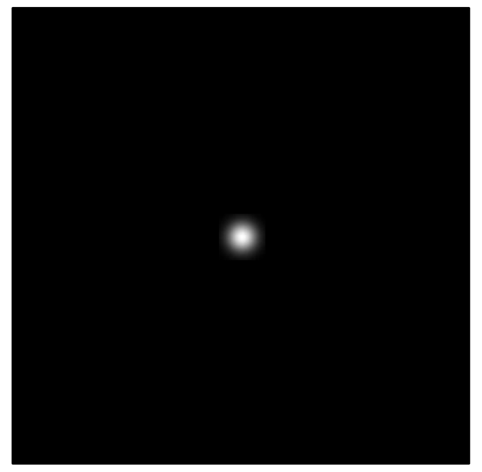
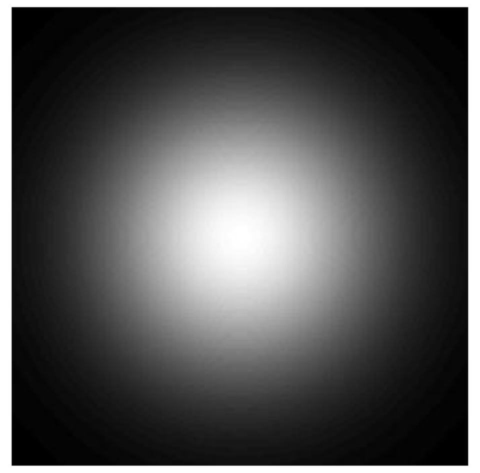
1 Visual localization precision decreases as the size of an object increases, but it is unclear as to whether the same is true for audition.

Sound localization in mammals is performed principally based upon three cues generated by the geometry of the head: the width and mass of the head introduce differences in time and intensity between the two ears (ITD and ILD), and the shape of the pinna selectively alters the spectrum of broadband sound transmitted to the ear drum (notably forming spectral notches). ITDs and ILDs provide localization information in the horizontal plane containing the interaural axis (i.e. in azimuth), and spectral notches provide information regarding elevation and front to back discrimination. Due to the acoustics of the head, it was predicted, and psychophysically confirmed, that ITDs are utilized below ~1 kHz, ILDs above ~3 kHz, and spectral notches above ~4 kHz.



Based on this understanding, it is easy to predict the location of an ideal, distant sound source along the horizon. Sound at some angle from center will generate a reproducible ILD and ITD, regardless of distance. Sources and listening environments, however, are never ideal.

Sound is rarely produced by a single point source. Instead, sound may originate from more than one point, or from a source that exhibits a substantial spatial extent. These factors contribute to the subjective assessment of sound characterization.



What constitutes the size of an auditory object, and does size affect localization? This is the case for vision; the precision with which the center of a large illuminated ball may be located is lower than for a smaller source (e.g. right top vs bottom). Acoustically, no known cues are present that would provide information as to the width of the source, thus we would not expect a listener to be able to discriminate between two similar, but differently sized sound sources. However, to the best of our knowledge, no test of this effect has yet been performed

2 The goal of our study was to test whether auditory localization ability is dependent upon the spatial extent of the sound source.

Subjects:
Seven young adults (3M, 4F) with normal hearing and vision.

Experimental Apparatus:

- **Test chamber (a, right)**: Dark, echo-attenuated room.
- **Head orientation**: Head fixed with a bite bar 2 m from, and facing the center of, a semi-cylindrical screen of black speaker cloth.
- **Target positioning:** Two-axis robotic arm with a range of 50 horizontal and 25 vertical re subject's "cyclopean eye".

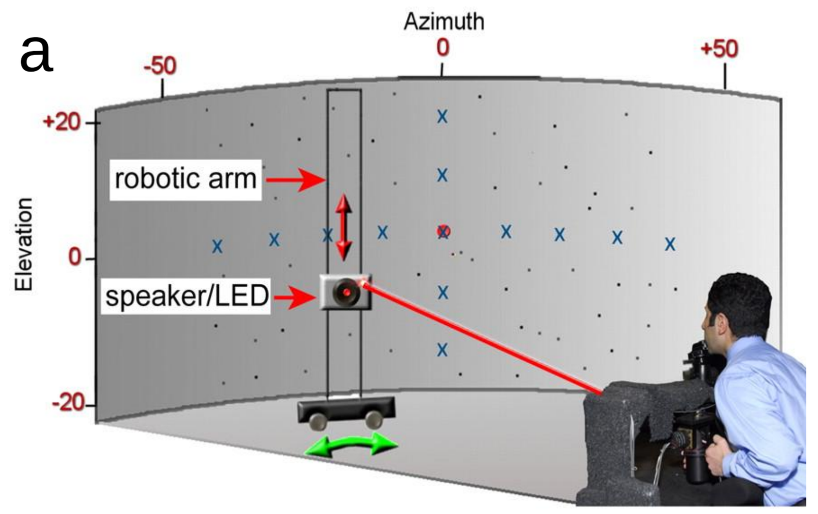
Stimulus and distractor characteristics

- **Target Field:** Semi-random locations (**b,** *black* symbols) superimposed on **multi-sampled (x10) locations** at 10 intervals along primary meridians (blue X's in **a**; *red* symbols in **b**).
- **Auditory targets:** band-limited noise bursts (150 ms, 10 ms r/f time, 0.2 - 1 kHz), 75 dB SPL (RMS; N_0 = 46 dB SPL), presented continuously at 5 Hz during each trial.
- **Auditory source:** 2-way 10 x 4 inch (25.4 x 10.2 cm) elliptical speaker (Pioneer TS-A4103).

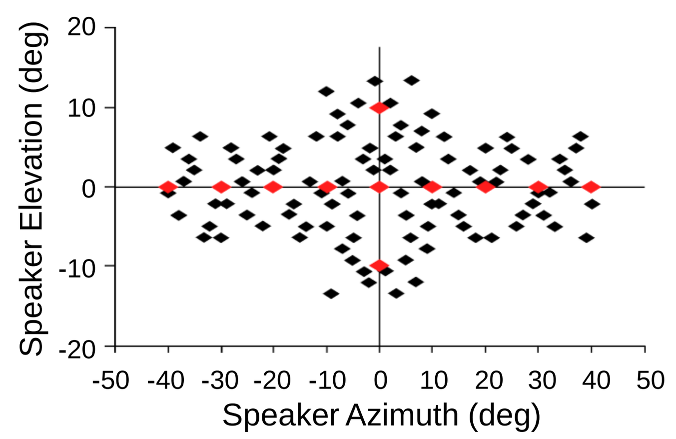
Experimental Paradigm

Subjects were instructed to point towards the source of the sound as quickly and accurately as possible with a laser pointer mounted to a large, featureless, 2-axis joystick. A white noise masker was presented by separate speakers bilaterally during robot movements in order to conceal the target location. The auditory target and laser pointer were turned on concurrently at the beginning of each trial, and remained on until the subject localized the target, signaled by button press.

a



b



c

3 Theoretical Background: The directivity of a baffled, circular piston depends upon speaker size and sound frequency.

- A listening point is in the far field when $r>R_0$, where the Rayleigh distance is given by:

  $R_0=ka^2/2$,
  a is the radius of the source, and k is the wave number:

  $k = 2\pi f/c_0$.

- The pressure at any point (L), a distance r from the center of a vibrating piston (radius a, on the x-y plane), at an angle θ is:

$$p(r,\theta;t)=\frac{ja\rho_0 c_0 u_0}{r}\frac{J_1(ka\sin\theta)}{\sin\theta}e^{j(\omega t-kr)},$$

- Directivity of the output is given by

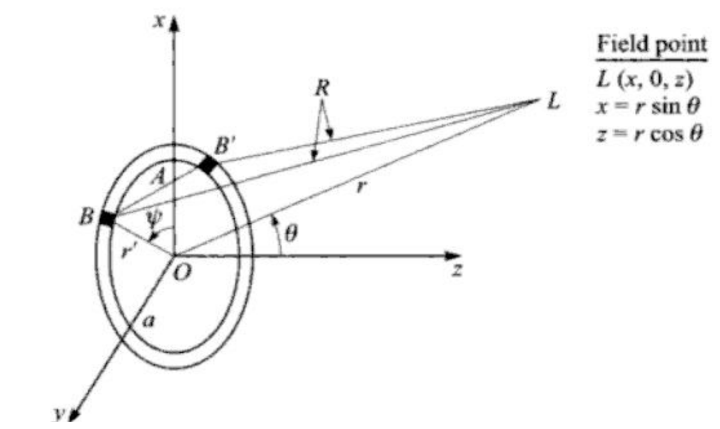
$$D(\theta)=\frac{P(r,\theta)}{P(r,0)}=\frac{2J_1(ka\sin\theta)}{ka\sin\theta}$$

where $J_1(x)$ is the Bessel function of the first kind (right center), of the first order.

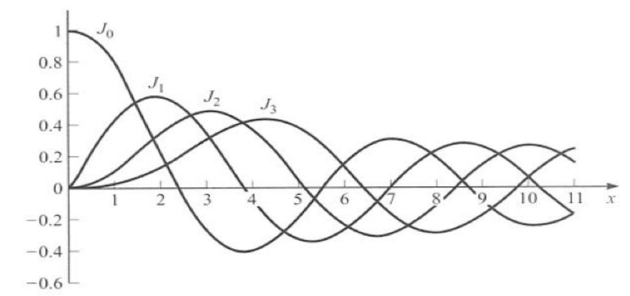
- Directivity goes to zero, producing an intensity null when:

  $\theta=\sin_{-1}(\alpha/ka)$.

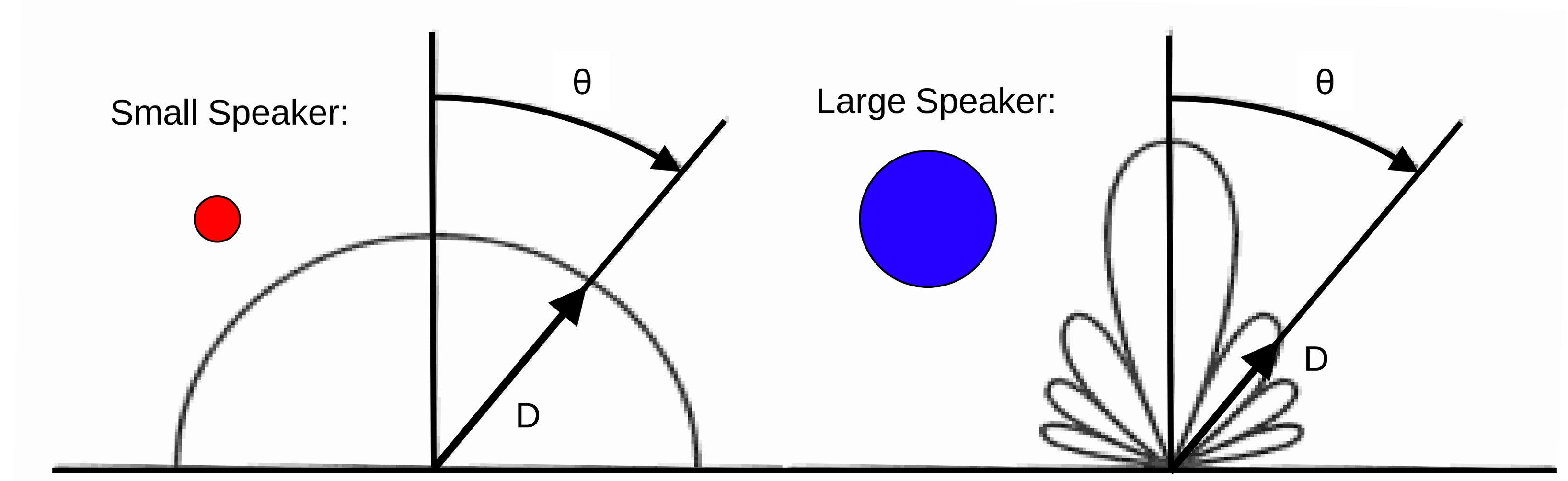
- The phase is equal at any two points L and L' (equidistant from the source), thus there are no temporal effects.
- **The principal effect of increasing the piston size is to increase directivity** (below).



Radiation from a circular piston, centered on the origin, at point L is calculated by integrating the radiation from an infinite number of rings, with radius σ and width dσ, over the radius of the disk, a. L is distance r away from the origin, i.e. center of the disk, and R away from two point on each ring, each with an area of dS (B and B'). L is on the x-z plane and the disk is on the x-y plane.

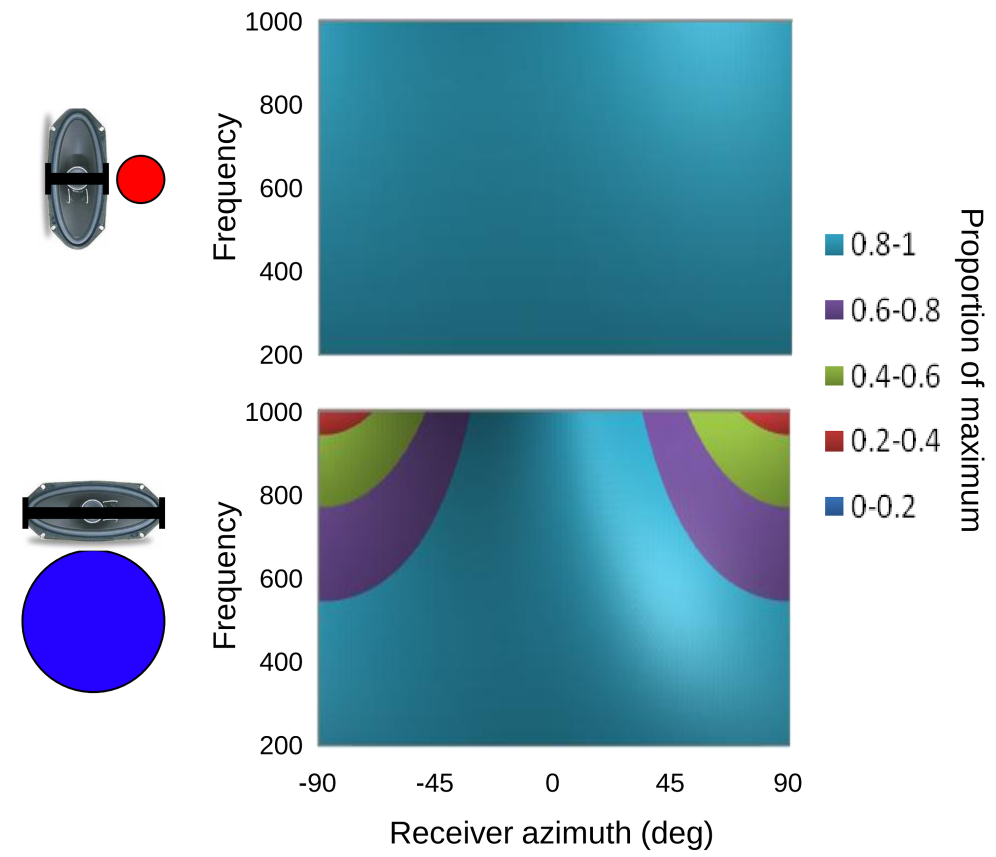


Family of Bessel functions of the first kind. Jm(x), m = 0, 1, 2, 3.



Figures from Blackstock, 2000.

4 Analysis of the speaker: No frequency nulls are generated at the frequencies of interest.



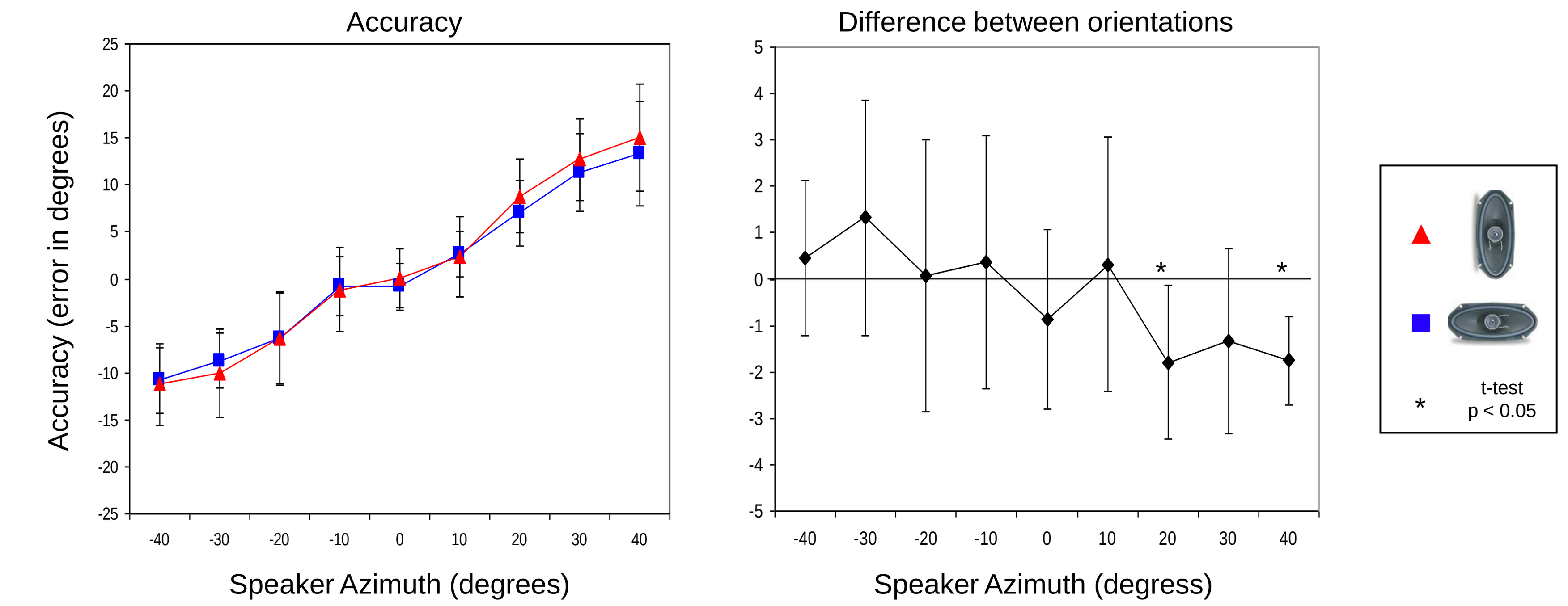
Directivity of the elliptical speaker is estimated as if it was being produced by circular speakers with diameters that match the large and small axes:

- Directivity vs frequency shows no nulls for our stimulus (left).
  - Small speaker (i.e. vertical; top): the first null is > 5 kHz.
  - Large speaker (horizontal; bottom): the first null is at 3 kHz.

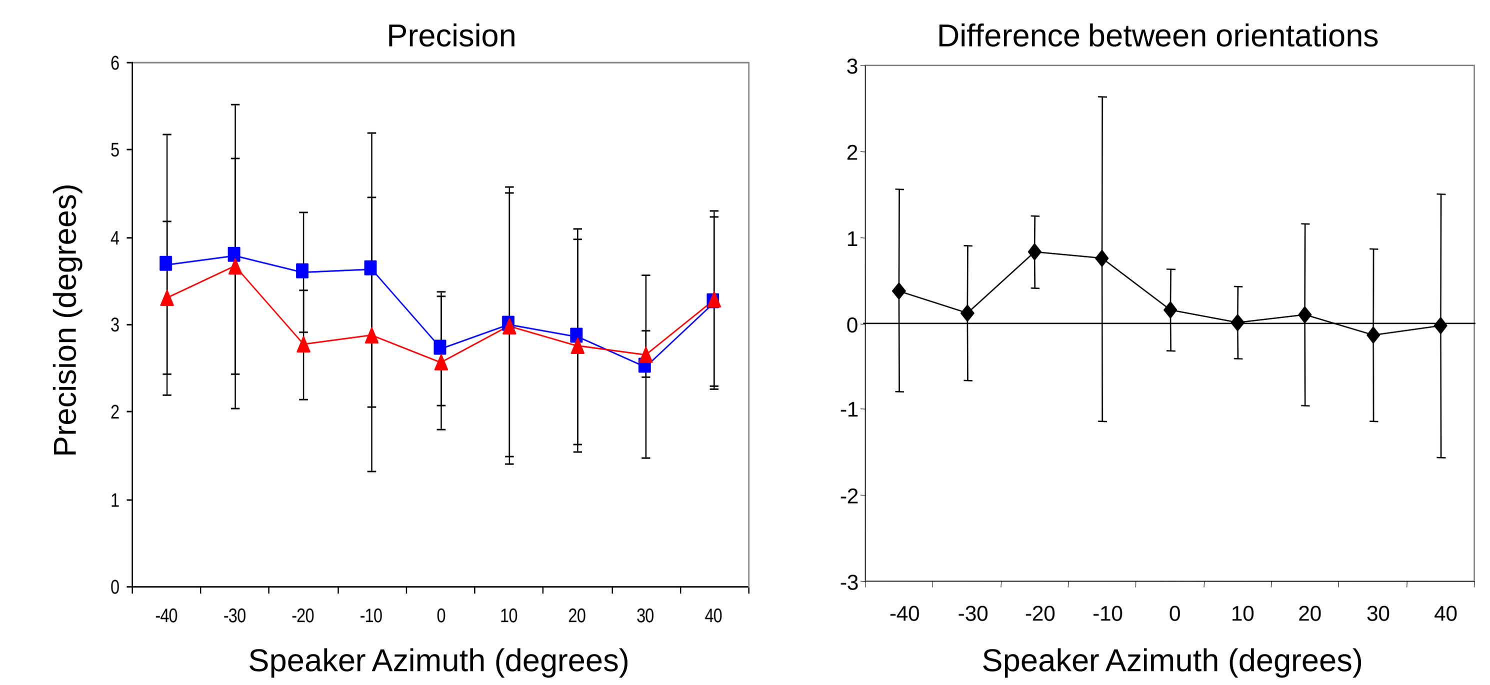
The speaker is pointed towards the center of the subject's head, thereby minimizing these effects.

- The intensity decrease is proportional at the two ears since directivity is symmetric.
- In order for a null to intersect the two ears (θ ≤ 2° for a 14 cm head at 2 m distance)):
  - The speaker must be very large: 6m diameter at 1 kHz (no longer in far-field).
  - Frequency must be very high: ~25 kHz for the wide speaker (above the audible range).

5 Localization accuracy (average error in azimuth) is no differences across speaker orientations.



6 Localization precision (standard deviation) is also equal for the two orientations.



- Levene's test for equality of variance reveals no significant differences at the p = 0.05 level.

7 Summary and Conclusions

- Acoustical analysis suggests that a listener will not be capable of determining source radius using two spatially separated receivers. However, just as with any complex physical system, many assumptions are made when performing the calculations necessary to describe the acoustics.
- The results of this experiment show that horizontal **localization of targets** in the far field is not affected by a >2-fold change in speaker width (10.2 to 25.4 cm).
- These results suggest that **sound source size does not affect far-field localization accuracy or precision.**

References

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Acknowledgements

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