
Absolute and relative cues for the auditory perception of egocentric distance

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Abstract. Three experiments were performed to examine the reverberation cue to egocentric auditory distance and to determine the extent to which such a cue could provide 'absolute', as contrasted with 'relative', information about distance. In experiment 1 independent groups of blindfolded observers (200 altogether) were presented with broadband noise from a speaker at one of five different distances (0.55 to 8 m) in a normal hard-walled room. Half of each group of observers were presented with the sound at 0 deg azimuth, followed (after a delay) by the identical sound at 90 deg azimuth. The order of presentation was reversed for the remaining observers. Perceived distance varied significantly as a function of the physical distance to the speaker, even for the first presentations. The change in the binaural information between the 0 deg and 90 deg presentations did not significantly modify the results. For both orientations, near distances were overestimated and far distances were underestimated. Experiments 2 and 3 were designed to evaluate how much prior auditory exposure to the laboratory environment was necessary. A 200 Hz square-wave signal was presented from one of three distances (1, 2, or 6 m) to observers who had either minimal room information or an exposure which included talking within the room. Perceived distance varied significantly with physical distance regardless of exposure condition.

1 Introduction

Perceived egocentric auditory distance is the apparent distance of a sound source from an observer. This perception of egocentric distance may be influenced by several different acoustic variables, among which are sound level, reverberation, binaural differences, frequency spectrum, and the type of stimulus used (cf Coleman 1963; Mershon and King 1975). These may briefly be identified as follows.

The sound-level cue usually results from the systematic changes in level which occur as a sound source of constant output is varied in physical distance in free space⁽¹⁾. Decreases in the sound level reaching the observer are expected to lead to increases in perceived distance (Gardner 1969). The reverberation cue involves the relative proportions of sound energy which reach the ear of the observer directly from the sound source and indirectly after a delay due to reflection from surrounding surfaces. Decreases in the ratio of direct sound to reflected sound occur with increases in physical distance in natural indoor settings and are, consequently, expected to lead to greater perceived distances (Maxfield 1931; von Békésy 1960).

Certain binaural time and level differences may also act as cues to distance for sounds which are displaced from the observer's midline. For example, sounds which are located at more than 75 deg azimuth and are relatively near the head may produce binaural time differences which are longer than any normally occurring time difference for a sound which is positioned at a greater distance (Gulick 1971). The precise limits for the functioning of the binaural cues are not clear and there has been some controversy as to their usefulness (cf Greene 1968; Hirsch 1968; Holt and Thurlow 1969; Molino 1973). Lambert (1974) has presented an analysis suggesting that a

⁽¹⁾ The term 'sound level' refers to the most commonly measured attribute of audio presentations, i.e. those variations in pressure which are measured by a sound-level meter. In the literature on auditory perception, this variable has often been mislabeled 'intensity', a term which correctly should be reserved for energy/time/area.

combination of the binaural cues could potentially be effective for distances as large as 6 m, if the observer were free to move his/her head systematically during the presentation. Although Simpson and Stanton (1973) failed to find any effects of head movement on distance judgment, their experimental procedures were not designed to provide a test of Lambert's particular hypothesis.

The frequency-spectrum cue results from changes in the relative proportions of high- and low-frequency content of a complex sound as its distance changes. A loss of high frequencies (relative to low frequencies) is expected to result in an *increased* perceived distance for a sound, if that sound is already perceived to be far from the observer, and to result in a *decreased* perceived distance, if the sound is initially perceived to be close [cf Coleman's (1968) dual-rôle hypothesis]. The type-of-stimulus factor describes effects which can occur for familiar sounds such as speech or frequently repeated presentations (Coleman 1962; Gardner 1969).

1.1 *Distinguishing absolute and relative cues*

Under the appropriate conditions each of the above factors seems capable of producing some changes in perceived auditory distance, when an observer is presented with changes in the value of the cue. This indicates that each of the factors can serve as a *relative* cue for auditory distance (cf Gogel 1968). Only recently, however, has anyone asked which (if any) of these factors can operate as *absolute* cues for auditory distance (Mershon and King 1975); are certain types of auditory information capable of determining systematic variations in perceived distance, in the absence of any immediately preceding presentation which could serve as an explicit comparison sound?

The necessary distinction between relative and absolute factors can be described in terms of a study by Coleman (1962). In that experiment an outdoor free-space environment was used and stimuli were 1 s bursts of broadband noise presented from one of several midline speakers. The design was simple but elegant; each of twenty observers listened to 100 stimuli and identified the apparent source for each trial. One group of observers received a sound from the 2.7 m speaker on the first and last trials, as well as intermixed with sounds from the other speakers during the intervening trials. For each of three other groups, the first and last trials were both from one of three other speakers at 4.6, 6.4, and 8.2 m. The data thus provide information concerning the perceived auditory distance of the same 'unfamiliar' sound (i) when presented as an initial stimulus, and (ii) when presented after a series of stimuli varying along acoustical dimensions correlated with source distance (i.e. varying in sound level and spectrum).

For trial 1 the four groups of observers reported more-or-less similar distances with an average value across the groups of 2.7 m⁽²⁾. This result is not surprising, since no one would expect an unfamiliar sound presented under such conditions to be judged correctly or even in a systematically varying way despite the differences in actual distance. For trial 100, however, the reported distances were approximately proportional to the true distances, presumably owing to the accumulation of comparisons among the many different stimuli.

The point to be made here is that the degree of systematic variation found after repeated presentations can indicate the effectiveness of any *relative* cues to auditory distance. This concern is different from whether or not *absolute* cues are available in a particular situation. The demonstration of such absolute factors requires that systematic variations occur *even on the initial presentations* to independent groups of observers.

⁽²⁾ Coleman's original data were presented in terms of the average error in identifying the true sound source from the column of visible speakers. The 'perceived' distance of each sound has been calculated to correspond to the actual distance of the source minus (or plus) the reported error.

The importance of this methodological distinction rests with a concern for understanding the bases for the perception of scale. While both absolute and relative factors may be important in structuring our usual perceptions of distance, absolute cues have the clear potential for providing scalar information; relative cues do not. Yet functionally it is often crucial not only to perceive that one sound is nearer or farther than another, but also to perceive whether a given sound is at a 'near', 'middle', or 'far' distance (i.e. to have some sense of scale, even if not perfectly veridical). The behavioral significance of hearing tire squealing while one is crossing the street is quite different when the sound is clearly perceived as being a block away than when it seems only a few feet away. Although a familiarity with the characteristics of certain sounds may provide the necessary variation in perceived distance for many situations (i.e. familiarity may provide an absolute cue), it is not necessarily the only source of scalar information.

1.2 Present experiments

Mershon and King (1975) suggested that the reverberation cue could serve as an absolute factor in determining egocentric auditory distance. In support of this conclusion, they presented data showing that independent groups of observers reported significantly different distances (on initial presentations) for near (2.7 m) and far (5.5 m) sources, when the sounds were presented in a semireverberant environment. Experiment 1 was designed to extend this work of Mershon and King to a wider range of physical distances (0.55 to 8.0 m).

Although the reverberation cue may be 'absolute' by the criterion just described (i.e. systematic variation on initial presentations), a separate problem remains to be considered. To what extent does the absolute nature of this cue depend upon prior perceptual information concerning the acoustical properties of *the experimental room itself*? Note that this possibility is not conceptually equivalent to the existence of a simple comparison between two (or more) stimulus 'presentations'. We are concerned in this case with the notion that a variety of indicators of room acoustics might exist in the experiment and might serve to calibrate (fully or partially) the perceptual variations from the reverberation cue. To what extent would some systematic variations across initial presentations still occur, if observers had only minimal prior exposure to the room? Are the variations dependent, for example, upon the previous exposure to human speech within the room? Such speech both contains information concerning its own distance (and might therefore serve directly as a comparison sound *if presented immediately prior to the test sound*) and provides an excellent basis for specifying certain acoustical characteristics of the space in which it occurs. Experiments 2 and 3 were designed to study this problem.

Although it has long been customary to obtain measures of auditory distances by having an observer choose which of a visible array of loudspeakers produced a given sound (e.g. Coleman 1962), that procedure was not followed in these studies. Mershon and King (1975) have discussed the importance of avoiding simultaneous visual information in experiments concerned with the perception of auditory space, since this method may influence the apparent positions of the sound directly or may modify the reports through a 'cognitive' bias. Thus, in the present research the observers were blindfolded throughout the presentations and perceptual reports were obtained by having an observer write his/her response or report orally.

In addition to the reports of perceived distance, some judgments of loudness were also gathered (in experiment 1) in anticipation of later research into the relationships underlying loudness constancy, a phenomenon more often noted casually than studied systematically (cf Ross 1975).

2 Experiment 1

2.1 Method

2.1.1 Apparatus. Stimuli were 5 s presentations of broadband noise (generally <7 kHz) prerecorded from a Grason-Stadler (model 901-B) noise generator and reproduced with a Sony (model 530) tape recorder connected to a standard Smaller Advent Speaker. The presentations were timed automatically by an electrically driven cam timer. (Although the rise time of the signal to the loudspeaker averaged 1–2 ms, no noticeable transient sounds could be perceptually separated from the random noise stimulus.) The speaker cabinet was centered at standing ear level (1.6 m from the floor) at one of several distances positioned along the lengthwise midline of a large, semireverberant room (10.6 m long $\times$ 7.2 m wide). The ceiling height of the room varied from approximately 3.5 m over most of the room to a low of 2.7 m under an overhang at one end. The room was constructed from standard hard building materials and was empty except for the experimental apparatus and for a few tables, chairs and cabinets along the edges⁽³⁾.

The speaker was located at one of five different distances from the observer's position: 55, 100, 200, 400, or 800 cm. Regardless of the distance of the speaker, the noise was always presented at an *A*-weighted sound level of 60 dB, as measured from the observer's head position with a General Radio sound-level meter (type 1565-A). The observer stood inside a hospital 'walker' located about 1 m in front of one end wall. A small writing table was attached to the front of the walker. The overhead lights in the room were out during the entire experiment, although sufficient light was provided by a small lamp so that the observer could be seen at all times.

2.1.2 Subjects. The observers for experiment 1 were 200 introductory psychology students participating as a course requirement. It was requested that they have normal hearing in both ears, although no test was made to verify this. All were naive with regard to the purpose of the experiment.

2.1.3 Procedure. Observers were met outside the laboratory. They were given preliminary instructions and blindfolded before being led to the walker, given additional instructions about the task, and provided with a large pad of paper and a pencil. They were informed of the direction from which the sound would come.

⁽³⁾ Since this study concerns the reverberation cue to egocentric distance, it is useful to specify the relevant acoustical characteristics of the test room more explicitly. This may be done by presenting the reverberation times for each of several frequency bands. Although this reverberation time (*T*) is defined as the time it takes for a sound to decay 60 dB after the termination of the source, measuring such decay time directly can be difficult. Fortunately, it is possible to determine *T* indirectly by measuring the 'critical distance' for each of the representative set of frequencies. To measure the critical distance (r_c) one establishes a constant noise source and measures the decay in the sound level with increases in distance from the source. The r_c value corresponds to the distance at which the contributions of the direct and the reverberant sound fields are equal (i.e. that point which yields a measured sound level exactly 3 dB greater than the asymptotic level of the reverberant field alone, which is achieved when distance is increased sufficiently). The r_c value may be determined quite readily from a plot of sound level as a function of log distance, and may then be used to determine *A* (the room constant) by the relationship $A = (16\pi r_c^2)/Q$ in which *Q* may be assumed to equal 1, if the source used is centrally located and not highly directional. Finally, *T* is calculated by the formula $T = 0.161V/A$ (where *V*, the room volume, and r_c have been measured in meters) or $T = 0.049V/A$ (where *V* and r_c have been measured in feet). For the test room of the present study an ILG Reference Sound Source was used. The calculated reverberation times were: 0.4 s (125 Hz), 1.1 s (500 Hz), 0.6 s (2000 Hz), and 1.0 s (4000 Hz). In an attempt to determine a single number to describe the relevant dimension, measurements of sound decrease with distance were also made by using the *A*-weighted scale. The *T* calculated by using the critical distance determined in this manner was 0.7 s. With the exception of the value at 125 Hz, which was rather short, these *T* values were approximately what one would expect from an empty, windowless classroom space of the sort used.

The experimenter then left the observer and walked quietly to a control bench positioned so that extraneous equipment sounds were not audible to the observer. Approximately 30 s after the end of the instructions, a 5 s presentation of the broadband noise was presented from the speaker at one of the five possible distances. Immediately following this presentation the observer recorded the "apparent distance" from himself/herself to the sound "in feet or inches or in some combination of feet and inches".

The observer also indicated the apparent loudness of the sound, in relation to a previously described scale from 1 to 1000, with 1 being defined as the faintest sound which he/she could hear and 1000 as the loudest sound to which it would not be painful to listen. The 1000-point scale was not used with the expectation that any such fine discrimination was possible, but rather because we felt that the use of a more customary 10-point scale should be avoided. Had a number range of 1 to 10 been used for loudness judgments, the reports of perceived distances (expected to occur mostly in the range from 1 to 10 ft) might have contaminated the reports of loudness. Reports of both distance and loudness were made by writing on the pad while still blindfolded.

Following completion of the tasks for the initial presentation, the walker was reoriented 90 deg left or right from its original setting, the writing pad was replaced with a fresh one, and the instructions were briefly restated. About 30 s after the end of these instructions another presentation of broadband noise was made from the same speaker position. Again, the observer recorded his/her reports on the pad. The only difference between the first and the second presentations, therefore, was the orientation of the observer with respect to the speaker and the intervening few minutes between the presentations.

A total of forty observers were presented with the sound from each of the five different speaker positions. Twenty observers in each group were presented with the first sound at 0 deg azimuth, twenty with the first sound at 90 deg azimuth. (The second presentation was always at the other possible orientation.) For the 90 deg orientation half of the observers were positioned with their right ear toward the speaker and half with their left ear toward the speaker. Observers were assigned to conditions by the order in which they reported to the laboratory. The conditions were arranged in randomly ordered blocks for the different distances and were counterbalanced within blocks for initial orientation and for the left-right position of the 90 deg presentation.

2.2 Results

Table 1 shows the data of the experiment for perceived distance (D') and table 2 shows the data for perceived loudness (L'). Since the results from verbal judgments of perceived distance often tend to be skewed, and since there was a good deal of variability in the use of the loudness scale, both mean and median values are given and statistical tests of inference are all nonparametric.

2.2.1 Perceived distance. It is clear from table 1 that the reports of D' differed across the five speaker distances. This variation in D' is significant for both first and second presentations of each of the two observer orientations (Kruskal-Wallis one-way analyses of variance, all $p < 0.001$), and is monotonic with respect to the physical distance [all $p < 0.05$ with the use of median D' and the nonparametric S statistic (cf Ferguson 1965)]. The closer presentations produced overestimations in median distance, which shifted to underestimations by the 800 cm distance. The results of individual observers were quite consistent with this pattern; thus, for the first presentation, 78% of forty observers reported a distance greater than 55 cm for the

Table 1. Perceived distance (D') of a sound from the observer as a function of the orientation of the observer, the physical distance to the speaker, and the presentation. All values are converted to centimeters.

	0° orientation					90° orientation				
	distance (cm)					distance (cm)				
	55	100	200	400	800	55	100	200	400	800
<i>First presentation</i>										
<i>M</i>	101.5	196.6	362.7	524.3	661.4	89.9	261.5	408.4	989.1	492.3
<i>s</i>	83.5	198.4	297.2	640.1	712.6	41.5	365.5	193.2	2024.5	240.5
mdn	91.4	106.7	304.8	411.5	411.5	91.4	121.9	335.3	381.0	457.2
<i>Second presentation</i>										
<i>M</i>	99.1	310.9	361.2	806.2	521.2	94.1	265.9	451.1	742.2	1226.8
<i>s</i>	61.8	653.4	214.5	1432.0	370.7	68.6	455.7	362.1	1277.4	2615.1
mdn	83.8	137.2	304.8	304.8	411.5	76.2	152.4	304.8	457.2	533.4

Table 2. Perceived loudness (L') of the sound as a function of orientation, distance, and presentation. All values are given to the nearest whole number of scale units.

	0° orientation					90° orientation				
	distance (cm)					distance (cm)				
	55	100	200	400	800	55	100	200	400	800
<i>First presentation</i>										
<i>M</i>	187	225	232	283	294	332	224	272	323	293
<i>s</i>	157	170	155	178	221	254	153	207	174	210
mdn	150	200	275	300	250	300	225	200	300	250
<i>Second presentation</i>										
<i>M</i>	284	240	268	288	246	249	269	255	358	303
<i>s</i>	236	151	213	179	170	159	196	149	209	208
mdn	200	200	200	275	275	300	225	300	375	300

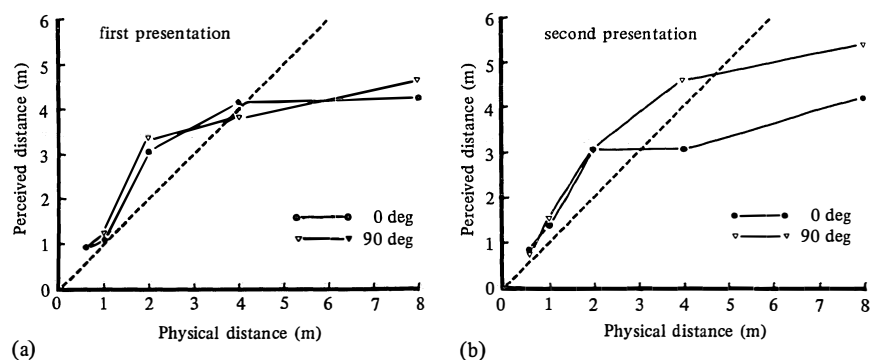


Figure 1. Median reports of perceived distance as a function of the physical distance to the speaker. (a) Results for the first presentation to each of the ten independent groups; (b) results for the second presentation to the same groups. Each observer's orientation was switched between presentations, either from 0 deg to 90 deg or from 90 deg to 0 deg.

nearest speaker and 82% of another forty observers reported a distance less than 800 cm for the farthest speaker. Each of these distributions is significant by a simple sign test ($p < 0.001$).

A comparison of the two orientations and an examination of the shape of the function relating perceived distance to speaker distance can be facilitated by considering figure 1. Clearly, there is no effect of the 90 deg difference in azimuth for any of the distances used for the first presentations. (The apparent differences at 400 and 800 cm for the second presentations are also not statistically significant.) Note that, for each curve shown, the perceived distance of the sound seems to reach some maximum value under the particular conditions of this experiment. This is quite reasonable, given the expected characteristics of the reverberation cue. As the source of the sound is moved to greater physical distances, less of the sound (proportionately) will reach the ear directly without reflection. The stimulation will come to consist almost entirely of reverberant (reflected) sound. Beyond that point, one would expect no further change in the value of the reverberation cue for additional increase in physical distance.

Although we did not use speaker distances of less than 55 cm, one might also ask what perceived distance should result if the reverberation cue reached the other possible extreme, the value for which the contribution of the reverberant field was negligible. Using anechoic (nonreverberant) conditions and with otherwise similar stimuli and procedures, Mershon and King (1975) reported D' values of 30–45 cm. Thus, as the physical distances become very short in the present situation, one should expect D' to reach some minimum value (i.e. 0.5 m or less). Extrapolations of the data in figure 1 appear consistent with this expectation.

2.2.2 Perceived loudness. The mean and median reports of perceived loudness are shown in table 2. Kruskal–Wallis one-way analyses of variance on the sets of individual judgments showed no significant differences for either the two combined 0 deg orientation presentations or the two combined 90 deg orientation presentations⁽⁴⁾. This outcome is not too surprising, given the enormous individual variability in the use of the loudness scale. Although there was some variability even in the median values of L' , one can note a tendency for greater physical distances to produce greater group reports of L' . This trend is significant ($p < 0.05$) for the combined 0 deg conditions, although not for the combined 90 deg conditions, with the use of the summed ranks from the Kruskal–Wallis test and the nonparametric S statistic (Ferguson 1965) for the comparison. Any such trend is, of course, interesting, since all stimuli were equated to 60 dB on the A scale, prior to the experiment. Although this result suggests a possible relationship between perceived loudness and distance, in the absence of the usual changes in sound level, such a claim is not warranted by the present data. It is quite possible that small differences in frequency spectra, as well as the obvious differences in the pattern of direct/reverberant sound, were sufficient to modify loudness directly despite attempts to equate gross sound levels across the given distances. A subsequent report will consider this problem in more detail and will describe a different methodological approach (Mershon et al, in preparation). Since the loudness data are of minor interest in the present paper, they will not be discussed further here.

⁽⁴⁾ Since the presentations at 0 deg involved more-or-less symmetrical binaural stimulation, compared with the presentations at 90 deg, the reports of perceived loudness are considered separately for each of these two orientations. This approach avoids problems, since it is well known that observers in a binaural experiment may choose to judge either overall loudness or the dichotic component loudnesses (cf Scharf 1969). In the absence of specific instructions to our observers, comparisons across different conditions of symmetry would be suspect.

3 Experiments 2 and 3

3.1 *Method, experiment 2*

3.1.1 *Apparatus.* Stimuli for experiment 2 were 5 s presentations of a 200 Hz square-wave signal from a Lafayette WA-44C audio generator, gated to have rise-fall times of 50 ms. Timing and gating were controlled by appropriate modules from Coulbourn Instruments. The amplified signal was presented to the observer through a 5 in Realistic speaker (7A6) mounted in a small panel held 1.6 m from the floor. (These new stimulus parameters were chosen to provide greater generality. Systematic variations in perceived distance on first presentations were still expected, although we realized that the exact quantitative form of the functions might be somewhat different from that in experiment 1.)

Experiment 2 took place in the same room as the first experiment. Only three speaker distances were used: 1, 2, and 6 m from the observer. All positions were along the lengthwise midline of the room and the observer was always oriented to face the sound source. Since small sound-level differences should not be critical in an independent-groups design, and since spectral variations may occur (e.g. in relation to different reflection paths) despite efforts to control sound level, speaker output was not adjusted for different distances. This resulted in *A*-weighted sound levels measured from the observer's head position of 65, 63, and 62 dB for the 1, 2, and 6 m sources, respectively. (Variations in *C*-weighted sound level were similar.)

3.1.2 *Subjects.* The observers for experiment 2 were 120 introductory psychology students participating as a course requirement. All reported normal hearing. None were familiar with the purpose of the experiment, nor had any of them served previously in experiment 1.

3.1.3 *Procedure.* All observers were met in a different room from that used for the experiment and were given initial instructions. Each observer was then taken to the door of the laboratory and blindfolded. At this point half of the observers (full-information condition) were led into the laboratory and read additional instructions within the room. These observers therefore received similar auditory information *about the room* as had the observers in experiment 1. The other observers (blocked-ears condition) were given their additional instructions outside the laboratory and were then asked to block their ears with their fingers (usually by pushing against the tragus) as they had been previously shown how to do. They kept their ears blocked during the entire time (about 1 min) that it took to guide them silently to the correct observation position and quietly shut the door to the room. To insure that any subsequent differences in results between the two conditions were not due directly to the immediately preceding pressure on the ears, all observers in the full-information condition were also asked to block their ears—but only after having obtained the information about room characteristics.

Once an observer was correctly positioned, with his/her ears blocked, the experimenter waited 10–15 s and then tapped lightly on the observer's shoulder. At the tap, the observer quietly lowered both arms and waited for the sound, which was usually initiated within 5 s after the ears were unblocked. Immediately following the sound, the observer orally reported its apparent distance in feet and/or inches. It is important to note that observers were repeatedly instructed not to say anything or to ask any questions until after they had made their report of distance. This turned out to be a difficult requirement and several observers were replaced for asking a question (e.g., “should I tell you now?”) before giving their report.

Six groups of twenty observers each were used, with each group receiving the sound from one of the three distances after one of the two conditions of preexposure to room

information. The different distances were presented in randomly ordered blocks of six and the occurrences of the two conditions were alternated within each block.

3.2 Method, experiment 3

Experiment 3 was a repetition of experiment 2 except for the following changes. First, each observer was allowed to choose his/her own method of ear blocking under instructions to find that technique which produced the greatest attenuation. This determination was made during the initial instruction period. Second, observers did not report orally. Instead, they used a grease pencil to write on their other hand. This procedure provided a virtually noiseless way to obtain a commitment which an observer could not change as a consequence of further auditory information (i.e., while starting to make the oral report itself). Third, sound levels measured at the observer's head position were 62, 63, and 62 dBA for the 1, 2, and 6 m distances, respectively. This adjustment (attenuating the presentation from the nearest speaker distance) was included as a check on the presumed unimportance of the variations in sound level used in experiment 2.

Observers for experiment 3 were a new group of 120 students from introductory psychology. With one exception they were unfamiliar with the experiment. (A final recheck of data records indicated that one observer had previously participated in experiment 2. Her report in experiment 3 has therefore been excluded from all analyses for that study.)

3.3 Results

The median reports of perceived distance for experiments 2 and 3 are shown graphically in figure 2, as a function of speaker distance and preexposure condition. It is readily apparent that a systematic variation in D' occurs for both conditions of both experiments. Each of these variations is significant at or beyond the 0.01 level by a Kruskal-Wallis one-way analysis of variance. None of the differences among the four separate curves are statistically reliable, although the difference between the two blocked-ears conditions at 6 m approached significance ($p < 0.10$, two-tailed, Mann-Whitney $U = 137$ with $n = 20$). While the form of the relationship between perceived and physical distance is somewhat different from that observed in experiment 1, there are also obvious similarities. Thus the closer presentations again resulted in perceived distances that were overestimations and the farther presentations produced underestimation. The availability of only three data points per curve, however, makes tenuous any decision about the precise shape of these functions.

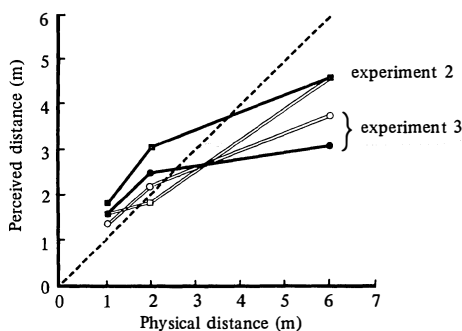


Figure 2. Median reports of perceived distance as a function of physical distance to the speaker in experiments 2 and 3. The open symbols represent data collected under conditions involving preexposures similar to those of experiment 1 (full-information conditions). The solid symbols represent data collected under conditions which involved a minimal preexposure to any information about the acoustical characteristics of the experimental room (blocked-ears conditions).

4 Discussion

The results of experiment 1 show that the perceived distance of a sound will vary systematically with source distance in a normally reverberant room, even when the different presentations are made to independent groups of observers. The separate functions for the 0 deg and 90 deg orientations show that the quantitative values (as indicated by group median data for first presentations) can be quite replicable. We take this outcome to be consistent with the description of the reverberation cue as an absolute factor in auditory distance perception.

The main conclusion to be drawn from experiments 2 and 3 is that prior speaking in the experimental room is *not* necessary for the operation of the reverberation cue. [We already know from Coleman's (1962) study that full perceptual information about the acoustical properties of the testing situation is not itself sufficient *in the absence of a reverberant environment* to provide any 'absolute' cues for auditory distance.]

Thus, we are left with two alternative possibilities: (a) sufficient information is contained in the stimulus presentation itself and its reflections to indicate variations in source distance systematically, if not veridically, or (b) if ambient sounds within the room are providing detailed information about room acoustics, they are able to do so very rapidly and at low levels of stimulation (ambient noise was usually less than 40 dB, *A*-weighted, and less than 50 dB, *C*-weighted).

A third possibility—that observers were gaining information about the room after the presentation (e.g., during their reports in experiment 2) and somehow adjusting their responses accordingly—can be ruled out from the results of experiment 3 in which *no* talking occurred until after the observer was committed to a particular value for his/her report.

A fourth possibility—that ambient noises could themselves serve directly as a 'comparison sound'—can be ruled out also. If such noises were effective as explicit comparisons then one might expect that many other experimental variables would also function as absolute cues. Yet we know of at least one good relative cue (sound level) which does *not* function in an absolute manner under similar conditions of ambient noise (Mershon and King 1975).

A final solution to the question of preexposure information about room acoustics will probably only be resolved by experiments utilizing carefully recorded sounds which can be presented over earphones in true isolation from the environment in which they occurred. That such an approach is possible is indicated by the results of Plenge (1974), who recorded sounds binaurally in one environment using a dummy head and reproduced perceptual features of that auditory space for observers wearing earphones.

4.1 Binaural cues in the present experiments

The use of a multiple-driver loudspeaker system (the Smaller Advent has two separate drivers within its cabinet) in a hard-walled room provided an acoustically complex stimulus. Although some binaural information about the speaker's distance was probably available, it is doubtful that observers could make use of this information as effectively as Lambert's (1974) analysis would predict, since observers were not permitted (nor observed) to move their heads during a presentation. Also, no significant differences in reported distance were found between the two orientations, despite the increase in potential information at 90 deg. It is thus difficult to believe that binaural cues alone could provide the basis for our results (although the results may contain a binaural component).

4.2 Range effects and other 'cognitive' adjustments

A difficulty common to studies with a repeated-trials design is the possibility that psychological 'range effects' (a form of response bias) can seriously influence the

results (cf Poulton 1973). Such range effects involve a tendency for responses in a psychophysical scaling experiment to be determined by the context in which different stimuli appear, as well as by the value of the individual stimuli themselves. With repeated presentations of the various stimuli, responses to extreme presentations tend to shift toward the center of the available range of values. Range effects can exist whenever explicitly or implicitly limited sets of stimuli/responses are involved in the psychophysical task.

In our experiments all important comparisons involved only the initial presentation. No explicit limitation in either stimulus or response range was mentioned to the subject. Our instructions stressed the importance of describing the *apparent* distance (i.e., "how far the sound seems") rather than a need for accuracy (e.g., "estimate where the sound is really located"). Nevertheless, spontaneous postexperimental comments support the belief that at least a few of our observers were operating under an implicit-range assumption, based in part on their expectations of room size, and modified their reports in line with these expectations. Other comments indicate that such range effects were not the only basis for conscious adjustment of the verbal reports. One response of "100 feet" was accompanied by the explanation that although the sound "seemed quite close", it had the quality of a "foghorn". Precise evaluation of the collective influence of all such cognitive adjustments must await the refinement of new techniques of measurement [cf Gogel (1976) and Mershon and Lembo (1977) for further discussions of this problem in the context of research on visually perceived distance].

4.3 A final caution

The results reported in this paper should *not* be considered as a claim that the perceived distance of a sound (even a 'first presentation' sound) will always vary in precisely the same manner, regardless of the particular situation. The observed functions with their patterns of over- and underestimation are, of course, limited to the single acoustical environment tested. Whether or not similar data will be obtained in rooms of other sizes, shapes, and reverberation times is unknown. Although patterns of systematic variation with over- and underestimation have been found in several studies of different reverberant spaces (cf Simpson 1972; Coleman 1968), few of these experiments have ruled out effects due to the accumulation of relational comparisons from repeated presentations.

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