

Auditory Reachability: An Affordance Approach to the Perception of Sound Source Distance

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The literature on perception of sound source distance reveals a wide range of listener accuracy. Most experiments have listeners perform unintuitive tasks, using unnatural sounds presented in impoverished acoustic environments. The present experiments implement an affordance paradigm for which listeners judge the "reachability" of a natural, live sound source in a familiar acoustic environment. Results reveal that listeners are quite accurate in judging whether the source is reachable and are sensitive to the advantage afforded by two vs. one degree of freedom reaches. Further analyses reveal that when scaled to an intrinsic bodily dimension, judgment differences between listeners disappear, implicating intrinsically scaled specificational information. A follow-up experiment explores the potential informational support for these judgments testing the usefulness of head movements and binaural hearing. Results reveal that whereas head movements had no bearing on either judgment accuracy or consistency, binaural information did enhance listener consistency. This could suggest that the allometric relation between interaural distance and arm length might provide a basis for auditory reachability judgments.

Although there is a vast literature on localization of sound sources in the horizontal plane (see Middlebrooks & Green, 1991, for a review), relatively little research has addressed perception of sound source distance. This is surprising because it is critical for animals to know the location of objects in both planes. For example, a bat uses distance information in timing its interceptive approach to a moth. The same is true of a visually impaired individual guiding his approach to switch off a radio. Sound source distance information is also used in guiding vision. For example, Guski (1992) proposed that knowing the changing distance of a looming object

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determines whether there is time to turn and visually localize the object, or whether avoidant behavior must be initiated first. Still, despite the clear ecological importance of the perception of sound source distance, relatively little research has addressed the topic.

The literature that does exist reveals a wide range of performance accuracy. Early research (Edwards, 1955) indicated that thresholds for noticing a change in source distance could be as high as 55 cm at distances of 1 m, and 1.76 m for distances of 8 m. Strybel and Perrott (1984) found that at distances of 6 m, listeners needed a change of 36 cm to hear a difference in distance, whereas at 1.52 m, a change of about 17 cm was needed. Recently, Ashmead, LeRoy, and Odom (1990) demonstrated impressively low difference thresholds at close distances. They found that at 1 m, practiced listeners had distance change thresholds of 5.8 cm. They attribute this high degree of accuracy to their use of a forced-choice listener task.

It is likely that the wide range of listener accuracy observed across studies is due to considerable differences in experimental design. These differences include the nature of the stimulus tested (e.g., live speech vs. recorded sounds; Gardner, 1968), the nature of the acoustic environment (echoic vs. anechoic; Mershon & King, 1975), and the nature of the task (method of limits vs. forced-choice; Ashmead, LeRoy, & Odom, 1990). To help sort out these issues, we report two experiments which attempt to "ecologize" the problem of sound source distance perception. These experiments implement a natural source presented in a familiar acoustic environment, and ask listeners to perform an intuitive judgment task. In addition, we test whether listeners judge distance in relation to their own body scale and explore what the information for body-scaled judgments might be. The theoretical motivation for this paradigm will be presented next, followed by a more detailed description of the methodology.

THE AFFORDANCE PARADIGM

For Gibson (e.g., 1966, 1979), the objects of perception are not just the objects and events in the world, but also what these things offer or afford an animal. These perceived *affordance* properties are specific to the animal and its particular set of action capabilities as well as the environmental layout. This perspective drives very different research questions from more standard approaches. For example, the affordance approach examines how animals parse the world perceptually based on anatomical and behavioral constraints. This *intrinsic* psychophysics contrasts with the *extrinsic* psychophysics of more traditional approaches which test sensitivities to animal-neutral physical dimensions such as distances, heights, and weights. Instead, the affordance approach asks observers to judge animal referential properties such as whether an object is reachable, traversable, or liftable.

The affordance paradigm has been used successfully to test the *visual* perception of the traversability of surfaces (Gibson et al., 1987), slopes (Kinsella-Shaw, Shaw,

& Turvey, 1992), stairs (Warren, 1984), and apertures (Warren & Whang, 1987), as well as object reachability (Carello, Groszofsky, Reichel, Solomon, & Turvey, 1989) and throwability (Bingham, Schmidt, & Rosenblum, 1990). Affordance research has also been conducted on the *haptic* perception of reachability (Solomon & Turvey, 1988; Carello, Fitzpatrick, & Turvey, 1990), throwability (Bingham, Schmidt, & Rosenblum, 1990), and the traversability of path gaps (Burton, 1992). This research has revealed that affordances can be perceived to the extent that perceptual judgments are scaled to observers' particular effector dimensions (e.g., leg length for stepability; arm length for reachability). Furthermore, it has been observed that participants are generally more accurate at judging affordance properties than animal-neutral dimensions (e.g., Bingham, Schmidt, & Rosenblum, 1990).

Integral to this approach is the determination of the body-scaled information that supports affordance perception. Implicit in traditional approaches (e.g., Ullman, 1980, as discussed by Carello et al., 1989) is the assumption that for perceptually guided action, there is a translational step from the extrinsic measurement of an environmental property to the intrinsic metric relevant to the effector organ. In contrast, the affordance approach proffers that environmental information is *directly* available in an intrinsic form relevant to effector/behavioral properties. This intrinsic information is based on the allometric relations between effector and perceptual system organs. As an example, the lawful relation between eye height and effector dimensions such as arm length and leg length (Davenport, 1944) can support visually informed affordance properties such as reachability (Carello et al., 1989) and stepability (Warren, 1984). It has been shown that information for eye height can be available through either a metric based on where the horizon divides the optic array (Sedgwick, 1983), or based on the optic flow induced by point of observation movement (Lee, 1974). Because of allometric relations, environmental properties can be seen in units of eye height as well as in units of the effector organs. Thus, information about the perceptual system also serves as body-scaled information about the effectors. This allows affordance perception to occur directly without the need for a translational step from an extrinsic to intrinsic informational form.

Although a good deal of research has been conducted on the visual and haptic perception of affordances, very little research has been specifically designed to test auditory affordance perception. (See Gaver, 1993, for work on auditory event recognition from the ecological perspective.) However, it is known that listeners can perceive action relevant properties through sound. This is evidenced by research in obstacle avoidance (e.g., Strelow & Babryn, 1982; Supra, Cotzin, & Dallenbach, 1944), aperture traversability (Passini, Dupre, & Langlois, 1986), and looming sound source avoidance (for reviews, see Guski, 1992; Rosenblum, 1993). The current study uses the affordance paradigm to test accuracy in the perception of sound source distance. In our experiments, we ask listeners to judge whether they can reach a sound source. It was expected that this more intuitive task would

elicit behaviorally appropriate judgments. In this same spirit, the stimulus tested was a natural, live sound presented in a familiar acoustic environment with reflectances. This contrasts with most other auditory distance research¹ which has used electronically generated stimuli played through loudspeakers and often presented in unnatural acoustic environments (sound attenuated or anechoic chambers).

Some previous research has been conducted on auditory reachability. Clifton and her colleagues (Clifton, Perris, & Bullinger, 1991; Litovsky & Clifton, 1992) used a reaching methodology to test sound source distance perception in infants. These researchers tested 7 month olds in a darkened room and used a shaking rattle as the auditory stimulus. They found that infants reached more often for a rattle that was 15 cm away, than one positioned 60 cm away. In a follow-up experiment, Litovsky and Clifton (1992) tested adults using a similar methodology. The adults displayed high accuracy in judging these source distances through verbal *near-far* judgments.

Our experiments borrow from the methodologies of Clifton et al. (1991) and Carello et al. (1989) who examined visual reachability perception. For both experiments, the auditory stimulus is a shaking rattle similar to that used by Clifton et al. (1991). Unlike Clifton's experiments however, we test substantially more than two (near and far) source distances. Also, to examine whether auditory reachability judgments are scaled to arm length, Experiment 1 tests groups of tall and short listeners (Carello et al., 1989). Experiment 1 also applies two different behavioral constraints to the task. Listeners are asked whether they can reach the sound source by (a) simply extending their arm and (b) extending their arm and bending forward at the waist. This manipulation is included to test whether listeners can anticipate the functional consequences of these tasks and perceive the advantage provided by a 2-*df* reach (Carello et al., 1989).

Experiment 2 was designed to investigate the body-scaled informational basis for auditory reachability judgments.

EXPERIMENT 1

Method

Participants. Twenty-four students from the University of California, Riverside participated in the experiment. Most of the participants received credit for an introductory course in psychology; others received payment for their participation. To test the influence of arm length, two participant groups were selected on the basis of their height (Carello et al., 1989). One group consisted of six males

¹The term *auditory distance research* (or *literature*) is used here to refer to the research conducted on the perception of distance through auditory means. The term should not be taken to imply that dimensions of the auditory signal are perceived as such.

and six females of less than 163 cm in height whereas the other group consisted of six males and six females over 173 cm in height. Although these two populations exclude a significant portion of the general population, they do provide an efficient means to test the body-scale question. All participants reported good hearing.

Stimuli. The sound source consisted of a rattle made up of a plastic box (9.75 × 9.75 × 2.5 cm) containing paper clips. The box was attached to a wooden pole which was inserted into a mechanical chemical shaker. A sound insulating box was constructed around shaker to dampen its sound as much as possible. The shaker rotated the pole approximately 90° thus rattling the paper clips inside of the box. The rattle oscillated at approximately 5.1 Hz. The average intensity of the rattle shakes was 72 dB SPL (A-weighted) measured at the listener's head with the rattle positioned 60 cm away. A spectral display of the rattle sound is shown in Figure 1.

The shaker-rattle apparatus was placed on a metal cart (height 73.5 cm) so that the rattle could be positioned at varying distances from the seated listener. The rattle was positioned in line with the listener's right shoulder at a height of 101.5 cm. The range of distances for the 1-*df* condition was from 38 to 110 cm in 8 cm increments from the listener's shoulder. The range for the 2-*df* condition was from 78 to 150 cm in 8-cm increments from the listener's shoulder.

The experiment was run in an acoustically normal room (2.85 × 2.78 × 2.74 m high) which was lightly cluttered. The walls were painted dry-wall, the ceiling consisted of commercial acoustical tile, and the floor was covered with standard linoleum tile. The shaker apparatus moved along the diagonal of this room relative to the listener who was seated in the corner.

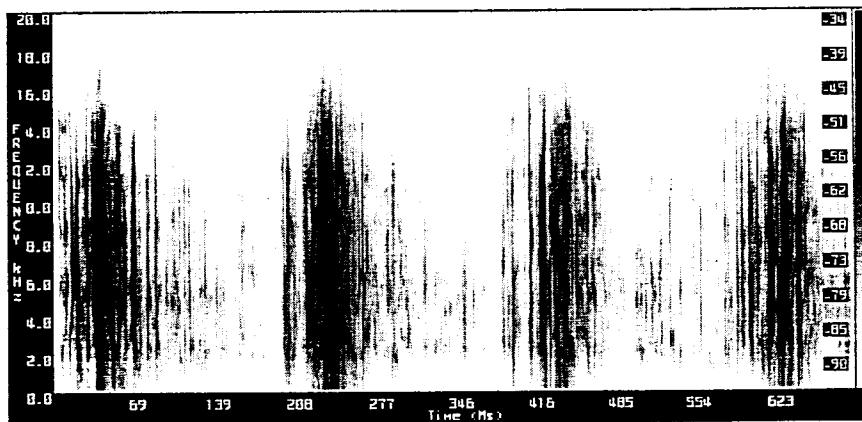


FIGURE 1 Spectral display of four shakes of the stimulus rattle.

Design and Procedure

When listeners first entered the experiment room, they were told about the experiment and were shown a rattle similar to the one used in the apparatus. Before the trials began, listeners were able to see the room but did not see the actual shaker and cart. Listeners were instructed that for each presentation, they were to judge—without actually reaching—whether the rattle was within the indicated type of reach, 1 or 2 *df*. For the 1-*df* condition, listeners were instructed to judge if they could reach the rattle if they were to simply extend their right arm straight out without rolling the shoulder forward and while maintaining contact with the back of the chair. In the 2-*df* condition, listeners were asked to judge if they could reach the rattle if they were to maximally extend their arm and bend from the hip while maintaining contact with the seat of the chair. These were the same instructions as used in the Carello et al. (1989) experiment. Once listeners provided their reachability judgment, they were asked to rate their confidence in their decision using a 5-point scale ranging from 1 (*least confidence*) to 5 (*greatest confidence*). After hearing the instructions, listeners were seated in the chair and blindfolded.

For each trial, the rattle continued shaking until a judgment was made and listeners were given as much time as they needed to make their judgments. Listeners were encouraged to move their head, and told that it might help with their judgment accuracy, but they were not required to perform head movements for the task. Between trials, the listeners heard white noise (73 dB SPL, A-weighted) over headphones to mask the sound of the moving apparatus. Informal pilot studies demonstrated that this noise was effective at masking any information about the direction of the moving cart.

The *df* conditions were blocked and half of the listeners received all of the 1-*df* trials first while the other half received the 2-*df* trials first. The experiment began with ten practice trials in the initial *df* condition. After the practice trials, listeners were given a chance to ask any questions about the procedure. This was followed by three trials each of the ten distances of the *df* condition. The trials were randomized with the restriction that no consecutive trials could be at the same distance. The listener was given a short rest halfway through the experiment and told that for the last half of the experiment they were to make their judgments using the other *df* condition. For the second half of the experiment, listeners were again given ten practice trials prior to the critical trial set. Listeners received no feedback at any time during the experiment and never touched the apparatus until all judgments were completed. When the experiment was completed, measurements were taken of the listener's arm length (shoulder to tip of thumb) and torso length (shoulder to the seat of the chair). In addition, their maximum reach was determined for each *df* condition by having them hold the rattle box out as far as they could while keeping to the constraints of the *df* conditions. The experiment lasted about 50 min for each listener.