The behavioral procedures used to determine the auditory sensitivity of three horses are described and illustrated by a line drawing. The average horse audiogram constructed from the data collected from these three horses is included. The hearing ability of the horse is compared to that of other mammals, and its practical relevance to the understanding of equine behavior is discussed.

The Hearing Ability of Horses

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□ In the course of comparative studies of mammalian hearing, we have recently begun to examine the hearing abilities of horses.[4] Our choice of horses as subjects for auditory research was based on theoretical considerations related to their size as well as to the fact that the auditory abilities of Perissodactyls were previously unknown. Yet in addition to its theoretical importance, a knowledge of the hearing abilities of horses has certain practical value. For example, the ability to specify the range of sounds which horses can hear is useful in identifying those sounds which a horse might respond to or be disturbed by. Furthermore, such information provides a starting point for any investigation of deafness in horses.

The purpose of this article is to describe the auditory sensitivity of the horse and the methods used to determine it. In addition, the hearing ability of the horse is discussed in terms of how it compares with that of other mammals as well as its relevance to the understanding of equine behavior.

Testing

There are several standard behavioral procedures currently used to determine the hearing abilities of mammals.[7] The procedure which we used here is known as a "go/no-go" procedure in which an animal is rewarded for making a specific response whenever it hears a sound. In our test, water was used as the reward and the horses were required to work each day to obtain their water. Three horses from 18 to 20 months old were tested: a Quarter horse gelding, an Appaloosa mare and a Welsh pony x Quarter horse gelding.

Specifically, a thirsty animal was led into an indoor stall and trained to place its nose on an "observing" plate located in front of a loudspeaker (Fig. 1). A 3-second pulsing tone was then presented at random intervals from 3 to 27 seconds apart. Once the tone occurred, the horse was required to break contact with the observing plate and touch a "reporting" plate within 3 seconds after the

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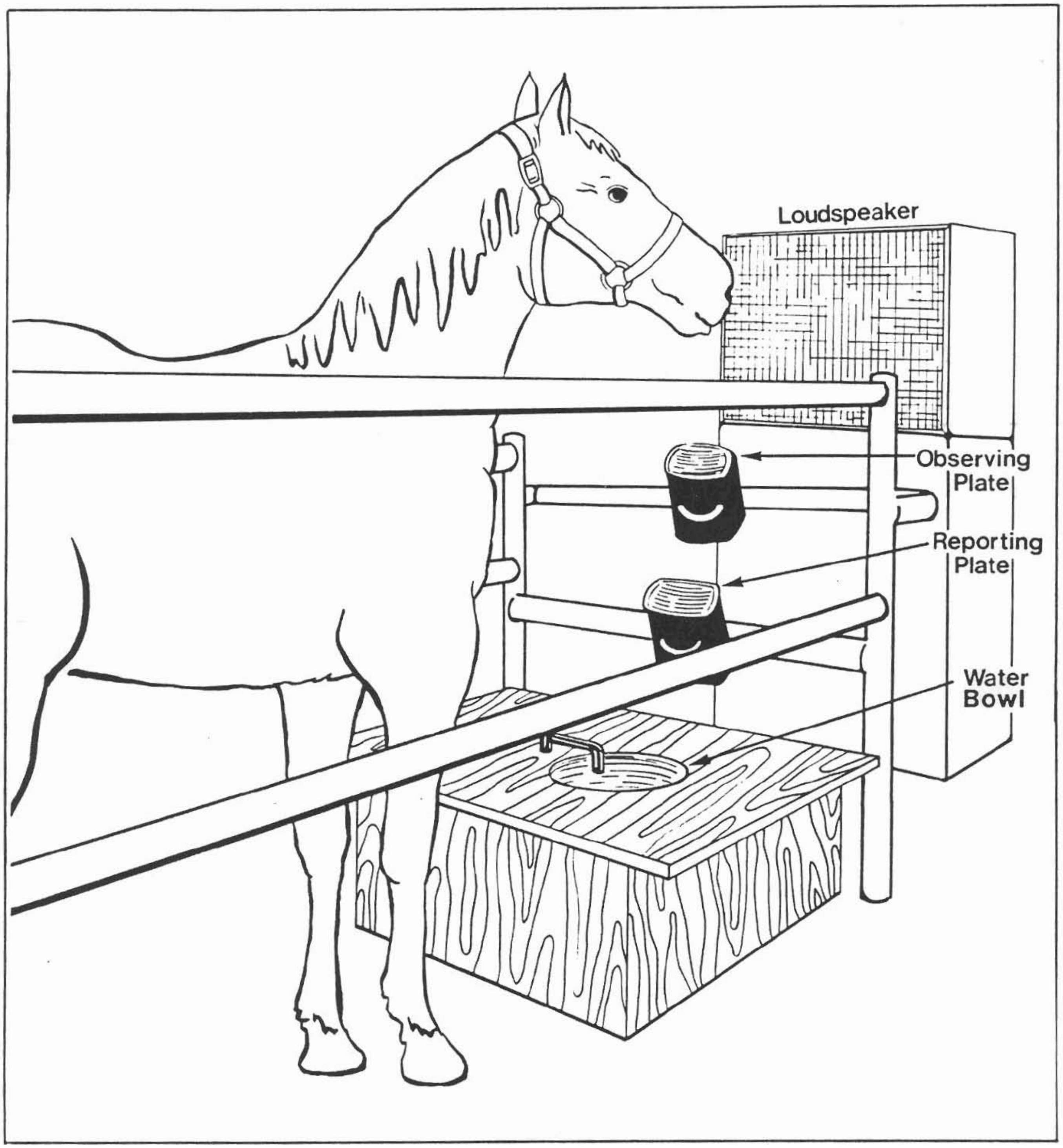

Fig. 1 — Stall and loudspeaker arrangement used to test hearing in horses. The animal was trained to place its nose on the observing plate and listen for a tone. Tones were presented at random intervals and the animal was given a water reward for breaking contact with the observing plate and touching the reporting plate within 3 seconds after onset of tone.

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onset of the tone. Correctly detecting the presence of a tone was rewarded by delivering about 250 ml of water into a bowl located below the reporting plate. However, if the horse responded when no tone was present, it was given a short wait or "time-out" during which testing was halted for about 15 seconds. Because the animal could not get water during this period, the time-out acted as a mild punishment.

Once an animal had reliably learned to report the presence of a tone, threshold testing was begun. This consisted of gradually reducing the intensity of a particular tone until the animal could no longer detect its presence. The animal's threshold for that tone was then defined as the intensity at which the tone was detected half of the time. Thresholds were then determined for tones of various frequencies taken in octave steps across the horse's hearing range. These thresholds were then used to construct an audiogram.

It should be noted that determining an audiogram that is to be representative for a species is a lengthy procedure. In our project it took 8 to 10 weeks to train and test the horses. For simpler determinations of whether or not an animal is deaf, it is sometimes possible to use a startle reaction to sounds[8] or brainstem auditory-evoked responses.[6]

Horse Audiogram

The auditory thresholds of the three horses were averaged at each frequency and the resulting average horse audiogram is shown in Figure 2. In this figure, each point represents the lowest intensity at which a particular frequency could be detected. Thus, large decibel values indicate that a tone had to be fairly intense before it could be detected, while small values indicate that a less intense tone could be heard. (Because sound, like temperature, is generally measured on a scale which has no absolute zero, negative values indicate only that the intensity of a sound is less than the 0 dB reference level used here.)

The horse audiogram exhibits the charac-

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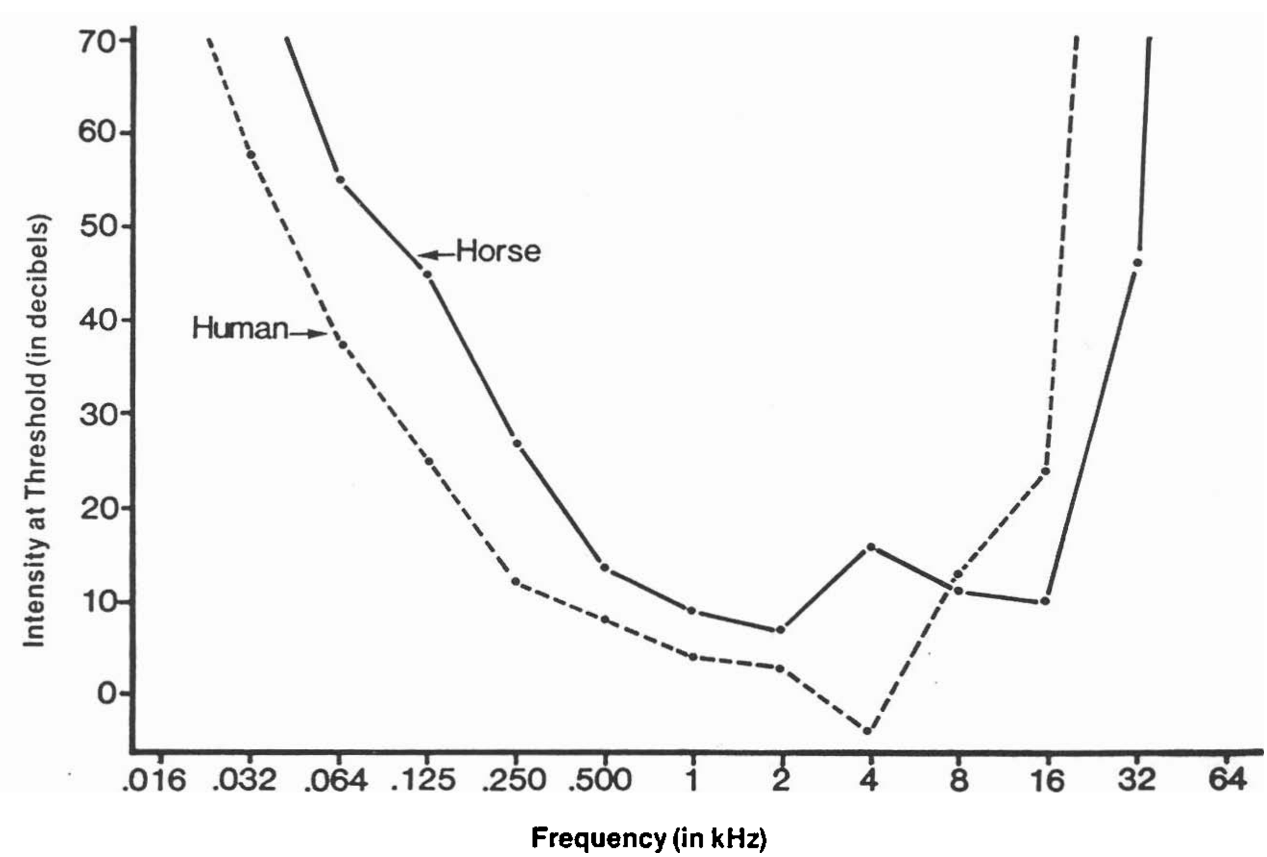

Fig. 2 — The audiogram for horses is represented by the solid lines, while the audiogram for humans,[1] shown for comparison, is represented by the dashed line. The dots show the average lowest intensity at which a particular frequency could be heard. Note that while the two audiograms are somewhat similar, horses have better high-frequency hearing, while humans have better low and mid-frequency hearing.

teristic shape of mammalian audiograms. Beginning at the low-frequency end, the audiogram shows that auditory sensitivity improves gradually as frequency is increased to about 500 Hz. At this point the audiogram levels off with a range of best sensitivity extending from about 1 kHz to 16 kHz with a slight dip in sensitivity at 4 kHz. Above 16 kHz, sensitivity decreases rapidly until an upper limit of audibility is reached. Overall, the practical hearing range for the horse extends from 55 Hz to 33.5 kHz, which are the lowest and highest frequencies that are audible to horses when the sounds are at an intensity of 60 dB (referenced to a 0 dB level of 20 microNewtons/meter^2).

Comparing horses with humans, it can be seen that while most sounds audible to horses are also audible to humans and vice versa, several differences do exist (Fig. 2). First, horses are somewhat less sensitive to low-frequency sounds than humans, whose low-frequency range extends down to 29 Hz (at 60 dB). Second, this difference extends into the midfrequency range from 500 Hz to 8 kHz where it can be seen that humans' lowest threshold of -4 dB at 4 kHz is significantly lower than the horse's lowest threshold of 7

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dB at 2 kHz. However, above 8 kHz horses are clearly more sensitive than humans, whose 60 dB high-frequency hearing limit is 19 kHz.

Such differences in hearing between different species of mammals is not unusual. For example, the Indian elephant[3] has a hearing range of 17 Hz to 10.5 kHz with a best sensitivity of 8 dB at 1 kHz, while wild house mice[2] hear from 2.3 kHz to 92 kHz with a best sensitivity of -10 dB at 16 kHz. Thus, though horses are not particularly sensitive at their frequencies of best hearing, they are not unusual among mammals.

Discussion

A knowledge of the auditory sensitivity of horses is helpful to the understanding of equine behavior in at least two ways. First, it makes possible the prediction of whether a particular sound will be audible to horses. Second, it is a necessary part of investigating the effects of hearing loss.

Given the frequency and intensity of a particular sound, it is possible to determine whether it would be audible to horses by referring to their audiogram. For example, the question occasionally arises as to whether horses might be affected by the various ultrasonic rodent or pest repellers currently on the market. As Figure 2 shows, horses are able to hear sounds in the ultrasonic range which are inaudible to humans. As a result, they would be able to hear those ultrasonic repellers which emit sounds between 20 kHz and 40 kHz, depending on how loud and how close the repeller was to the horse. However, horses are about 40 dB less sensitive to these sounds than most rodents[2] so it is possible for pest repellers to emit sounds that would be quite audible to rodents and yet faint or inaudible to horses.

Finally, the effect of deafness in horses is of particular concern. Not only might a hearing loss affect a horse's ability to respond to voice commands, but it could also interfere with the vocal communications which horses use in mating and in rearing their young.[9] The vocalizations of horses, like human speech,

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are predominantly low-frequency sounds with most of their energy located in the region below 4 kHz. As a result, a horse could suffer a high-frequency hearing loss which would not visibly affect its ability to hear those sounds used in communication. However, a hearing loss affecting the lower frequencies, as can occur from blockage of the auditory canal,[5] could significantly affect a horse's ability to respond to communication sounds. ■

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