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Short Communication

Hearing range of the domestic cat

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The behavioral audiograms of two cats were determined in order to establish the upper and lower hearing limits for the cat. The hearing range of the cat for sounds of 70 dB SPL extends from 48 Hz to 85 kHz, giving it one of the broadest hearing ranges among mammals. Analysis suggests that cats evolved extended high-frequency hearing without sacrifice of low-frequency hearing.

cat, audiogram, mammalian hearing, *Felis catus*

Over the years, a number of studies have reported behavioral audiograms for the domestic cat (e.g. [1–3,9–11,13,14]). Yet, of these audiograms, none has determined the entire hearing range of the cat and most have concentrated on the middle range of the audiogram. The most extensive study of cat hearing was conducted by Neff and Hind [11] who tested cats at frequencies ranging from 62.5 Hz to 60 kHz. However, the low thresholds obtained for the animals at these frequencies indicated that their limits of hearing had not been reached. Because cats are common subjects in physiological and anatomical studies of the auditory system, a complete knowledge of their hearing range is of practical significance. Furthermore, the lack of such information has prevented inclusion of the domestic cat in comparative analyses of mammalian hearing (cf. [5]). Accordingly, the purpose of the present study was to determine the high- and low-frequency hearing limits of the domestic cat.

Two mixed breed domestic cats (*Felis catus*) were tested using a conditioned avoidance procedure similar to that used elsewhere (for details, see [4]). Briefly, a thirsty cat was placed in a cage constructed of 1.27 cm hardware cloth (67 × 31 × 41 cm mounted on 77 cm legs) and trained to make steady contact with a water spout in order to receive a trickle of water (approximately 4 ml per minute). The animal was then trained to break contact with the spout whenever a tone was presented in order to avoid receiving a mild electric shock delivered through the spout and cage floor.

The test procedure consisted of presenting 2 s trials with 2.7 s intertrial intervals. Every trial was either a 'safe' trial during which no tone or signal was presented or a 'warning' trial during which a pulsing tone was presented. Warning trials occurred randomly from one to ten trials after the previous warning trial and were followed by shock. (Longer intervals between warning trials were randomly inserted to prevent an animal from using the time since the last warning trial as a cue.) For the purpose of quantifying an animal's response, the duration of spout contact was measured in 0.1 s intervals during the final one second of every trial. This measure of contact was then averaged separately for the entire population of silent or safe (S) trials and the tone or warning (W) trials for each intensity at each frequency. A measure of hearing could then be expressed in the form of a suppression ratio $(S-W)/S$ for each stimulus intensity. In trained animals this measure varies from near zero (failure to detect the tone) to unity (perfect detection).

Auditory thresholds were initially estimated by reducing the intensity of a tone in 10 dB increments until the cat could no longer distinguish tone trials from silent trials. Final threshold determination was conducted by presenting tones

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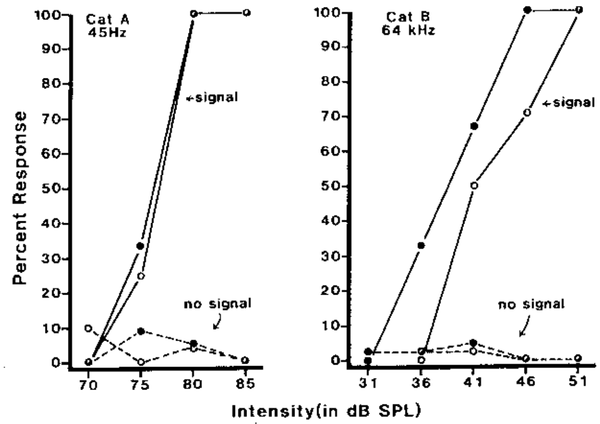

Fig. 1. Psychophysical functions for cat A (45 Hz) and cat B (64 kHz). The data represent two different sessions (filled and open circles) for each animal. ———, responses during the signal, or warning, trials (i.e., hit rate); - - - - - -, responses during the no-signal, or safe, trials (i.e., false alarm rate). The thresholds calculated based on the suppression ratios for cat A were 76 dB for both sessions and for cat B were 36 dB (●) and 39 dB (○).

varying in intensity by 5 dB extending from at least 5 dB below to 10 dB above the estimated threshold. Threshold was then defined as the lowest intensity that could be detected at the 0.01 chance level (binomial distribution) which was usually a suppression ratio of 0.25. Testing for a frequency was considered complete when thresholds obtained on at least two different sessions were within 3 dB of each other. An example of each animal's performance is shown in Fig. 1 which illustrates their hit and false alarm rates as well as the stability of their thresholds. Final thresholds were determined by combining the scores from these sessions which resulted in a minimum of 55 trials per intensity, 18% of which were warning trials.

Testing was conducted in a double-walled acoustic chamber (IAC, 2.7 × 2.5 × 2.0 m) the walls and ceiling of which had been covered with egg-crate foam to reduce sound reflection. Sine waves used to produce the tones were generated by an oscillator (Hewlett-Packard 209A), switched on and off by a rise–decay gate (Grason Stadler 1287), attenuated (Hewlett-Packard 350D), filtered (Krohn-Hite 3202), and led via either an impedance matching transformer or an amplifier (Crown D75), to a loudspeaker (a 38 cm woofer for frequencies of 500 Hz and below, a 7.5 cm wide range speaker for 1–2 kHz, and a ribbon tweeter for 4 kHz and higher). The speakers were located at ear level 1 m in front of the animal. This sound system was capable of producing undistorted tones with no significant harmonics from 32 Hz to 91 kHz at an intensity of at least 83 dB SPL.

In order to avoid switching transients the electrical signal was electronically switched with a rise–decay time of 100 ms for 32 and 45 Hz, 50 ms for 63 Hz, 25 ms for 125 and 250 Hz, and 10 ms for 500 Hz and above. Tones of 125 Hz and higher were pulsed at a rate of 2/s, 400 ms on and 100 ms off. Longer on and off times were allowed for the lower frequencies to compensate for the longer rise–decay times. The sound system was calibrated with either a Brüel & Kjaer (B & K) 1-inch (2.54 cm) microphone, sound level meter (B & K 2203) and octave filter (B & K 1613) or a 1/4-inch (0.64 cm) microphone (B & K 4135), preamplifier (B & K 2608), and filter (B & K 1613 or Krohn-Hite 3202). Sound measurements were taken in the position normally occupied by an animal's ears while drinking and care was taken to ensure that the sound field for all test frequencies was homogeneous in the area occupied by the animal. Finally, the intensity of the ambient noise in the test chamber was measured at one-sixth octaves throughout its measurable range. To reduce the level of low-frequency ambient noise in the sound chamber, the air conditioning system for the building in which it was located was turned off during testing of frequencies below 250 Hz.

The audiograms of the two cats are shown in Fig. 2. Beginning at the low frequencies, it can be seen that the animals were able to hear 45 Hz with an average threshold of 75 dB SPL. The sensitivity of the animals improved as frequency increased with the audiograms showing a very broad range of good hearing from 500 Hz to 32 kHz. Above 32 kHz, the animals' sensitivity decreased rapidly to 91 kHz at which frequency their average threshold was 80 dB SPL. At a level of 70 dB SPL, the animals' hearing thus spanned a range from 48 Hz to 85 kHz.

A comparison of the present audiogram with that of Neff and Hind [11] reveals several points of interest (Fig. 2). First, it can be seen that there is close agreement between the two audiograms in

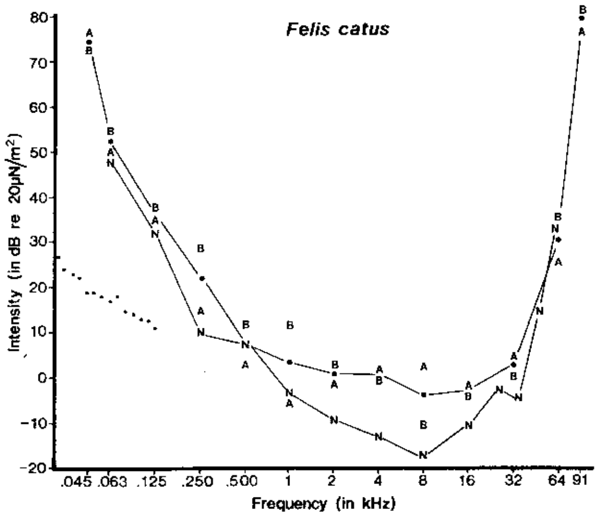

Fig. 2. Audiogram of two cats (A and B) compared with a previous cat audiogram (N) by Neff and Hind [11]. Dots indicate measurable background noise intensity.

the low-frequency range. Though Neff and Hind were concerned that their 62.5 Hz threshold might have been confounded by overtones, the average thresholds of the two studies are within 5 dB at this frequency. Second, in the midrange, the two audiograms show a noticeable difference especially at 4 kHz and 8 kHz where they differ by 14 dB and 13 dB, respectively. However, cats typically appear to differ in the midfrequency range with Neff and Hind's three animals differing by 17 dB at 4 kHz. Such variation between cats in the midrange is common even in more recent studies (cf. [1]). Indeed, one study found a 21 dB range in the thresholds of three cats at 8 kHz [12]. Thus, midrange variation is probably due to genuine differences in sensitivity rather than to procedural differences or sound field variation.

Finally, though Neff and Hind had to estimate the calibration for their sound measuring microphone for frequencies above 16 kHz, our results also confirm their high-frequency thresholds. For example, their average threshold of 33 dB at 60 kHz is quite close to our interpolated value of 29 dB for the same frequency. Overall, then, the present study confirms and extends the high- and low-frequency hearing limits which Neff and Hind described for the cat 30 years ago.

Comparing the hearing range of cats with those of other mammals it is now apparent that the cat has one of the broadest hearing ranges among mammals whose hearing is known. At a level of 60 dB SPL, the cat's hearing range is 10.5 octaves (as compared to the human hearing range of 9.3 octaves), a range which is barely exceeded only by cattle and porpoises [5,7].

Analyzing the cat's audiogram, it appears that its broad hearing range is due both to its good high-frequency and its good low-frequency hearing. In mammals, high-frequency hearing ability is correlated with functional interaural distance such that mammals with small interaural distances are better able to hear high frequencies than are larger mammals (e.g. [5,8]). This relationship, which is explained in terms of the need to localize sound, predicts that the 60 dB high-frequency limit of the cat would be 46.5 kHz. In actual fact, the cat's high-frequency limit is 78 kHz which is 0.8 octaves higher than expected and accounts for part of the cat's broad hearing range. More notable, however, is the cat's good low-frequency hearing. Among terrestrial mammals, low-frequency hearing is strongly correlated with high-frequency hearing such that mammals with good high-frequency hearing generally do not have good low-frequency hearing and vice versa (e.g. [4–6]). The cat, however, appears to have increased its high-frequency hearing without any sacrifice in low-frequency hearing. That is, while its high-frequency hearing limit leads to a predicted 60 dB low-frequency hearing limit of 595 Hz, the cat's actual low-frequency hearing is 55 Hz. Because 55 Hz is close to the value expected had the cat heard only as high as predicted by its interaural distance, it appears that the cat extended its high-frequency hearing without losing its low-frequency sensitivity.

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References

1 Costalupes, J.A. (1983): Temporal integration of pure tones in the cat. Hearing Res. 9, 43–54.

2 Elliott, D.N., Stein, L. and Harrison, M.J. (1960): Determination of absolute-intensity thresholds and frequency-difference thresholds in cats. J. Acoust. Soc. Am. 32, 380–384.
3 Gerken, G.M. and Sandlin, D. (1977): Auditory reaction time and absolute threshold in cat. J. Acoust. Soc. Am. 61, 602–607.
4 Heffner, H.E. and Heffner, R.S. (1985): Hearing in two cricetid rodents: Wood rat (*Neotoma floridana*) and grasshopper mouse (*Onychomys leucogaster*). J. Comp. Psychol. (in press).
5 Heffner, R.S. and Heffner, H.E. (1983): Hearing in large mammals: Horses (*Equus caballus*) and cattle (*Bos taurus*). Behavioral Neurosci. 97, 299–309.
6 Heffner, R.S. and Heffner, H.E. (1985): Hearing in mammals: The least weasel (*Mustela nivalis*). J. Mammal. (in press)
7 Johnson, C.S. (1967): Sound detection thresholds in marine mammals. In: Marine Bioacoustics, Vol. 2, pp. 247–255. Editor: W.N. Tavolga. Pergamon Press, New York.
8 Masterton, B., Heffner, H. and Ravizza, R. (1969): The evolution of human hearing. J. Acoust. Soc. Am. 45, 966–985.
9 McGill, T.E. (1959): Auditory sensitivity and the magnitude of cochlear potentials. Ann. Otol. Rhinol. Laryngol. 68, 193–207.
10 Miller, J.D., Watson, C.S. and Covell, W.P. (1963): Deafening effects of noise on the cat. Acta Oto-Laryngol. Suppl. 176, 3–91.
11 Neff, W.D. and Hind, J.E. (1955): Auditory thresholds of the cat. J. Acoust. Soc. Am. 27, 480–483.
12 Orr, J.L., Moody, D.B. and Stebbins, W.C. (1977): Behavioral system and apparatus for tone-detection and choice reaction times in the cat. J. Acoust. Soc. Am. 62, 1268–1272.
13 Sokolovski, A. (1973): Normal threshold of hearing for cat for free-field listening. Arch. Klin. Exp. Ohr.-, Nas.- Kehlk. Heilk. 202, 232–240.
14 Wakeford, O.S., Cavonius, C.R. and Brown, K.S. (1967): Measurement of auditory thresholds in the cat using positive reinforcement. Proc. 75th Ann. Convention, APA, 99–100.