Cite as: Funnell, W. R. J. and C. A. Laszlo (1974). "Dependence of middle-ear parameters on body weight in the guinea pig." The Journal of the Acoustical Society of America 56(5): 1551-1553.

Dependence of middle-ear parameters on body weight in the guinea pig

W. R. J. Funnell and C. A. Laszlo

BioMedical Engineering Unit, McGill University, Montreal, Quebec, Canada
(Received 1 September 1973)

We have investigated the dependence of several anatomical parameters of the guinea-pig middle ear on body weight, and thus on age. In particular, the volumes of the tympanic and epitympanic cavities are found to increase with age, with the tympanic cavity growing somewhat more slowly. The mass of the incus appears to be independent of body weight. These results are important for establishing the values of parameters used in mathematical models of the middle ear. They are also relevant to theoretical considerations of the significance of middle-ear resonances.

Subject Classification: 65.24, 65.20, 65.35.

INTRODUCTION

In mathematical models of the guinea-pig middle ear, two important parameters are the volumes of the tympanic cavity and of the epitympanum. To the best of our knowledge, the only quantitative data that have been published concerning these volumes are the average values of 0.20 cm^3 and 0.05 cm^3, respectively, reported by Mundie (1962). It is known, however, that the size of the head increases markedly with increasing age and body weight in the guinea pig (Bessesen and Carlson, 1923), and also that this species displays considerable age-independent variation of the size and degree of inflation of the lateral wall of the middle ear (Winge, 1888). Since the cavity volumes are important in determining the input impedance of the middle ear, their changes with age and their variability between individuals may be of importance in interpreting experimental results obtained from the guinea pig, and also in theoretical considerations of middle-ear function. The only previous quantitative published study of middle-ear-cavity growth and variability in any species concerned the human mastoid air cells, which were found to continue to grow until early adolescence, and to vary greatly in volume among individuals (Diamant, 1940).

Previously unpublished data are presented here concerning the variation of middle-ear volume with body weight in the guinea pig. These data were obtained in the course of studies of middle-ear impedance (Mundie, 1962; Funnell, 1972). Although for some purposes age would be a better independent variable than body weight, it is much more difficult to measure, and as far as we know such data are not yet available. The relationships between the volumes and body weight are themselves of interest for two reasons. First, they can easily be used to predict middle-ear volume for a given guinea pig, since the body weight is routinely measured anyways. Second, it is possible, on the basis of these relationships, to make statements about the effects of age, since information is available relating body weight and age in the guinea pig, as summarized in Fig. 1. Although there is quite a bit of variability, it can be seen that the body weight increases continuously with age over the range of animals commonly used in auditory research (200–600 g).

I. METHODS AND RESULTS

The volume data reported here are from two sources. The first is previously unpublished work by Mundie (1971); these are the results on which were based the above-mentioned average values. Mundie measured the volumes of the tympanic and epitympanic cavities by weighing the amount of mercury needed to fill them. The second source of data is our own experimental work, done as part of a mathematical modeling study (Funnell, 1972; Funnell and Laszlo, 1972). We measured the volumes by making silicone-rubber castings of the cavities, and then measuring the volumes of the castings with a specific-gravity bottle. The data from both sources are for ears that had been removed from the animal and air-dried for at least 24 hours.

In Fig. 2 the sum of the tympanic and epitympanic volumes is plotted as a function of body weight. Mun-

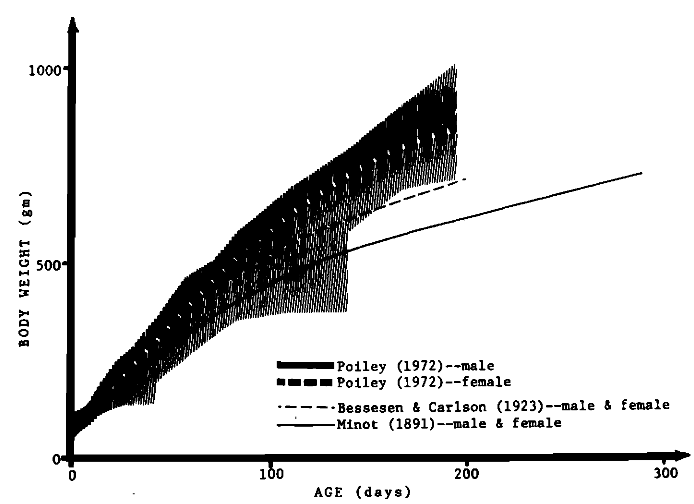

FIG. 1. Body weight of the guinea pig as a function of age. The curves shown are hand-smoothed representations of data from the three references cited. The two thick curves are from Poiley (1972), and show the difference between the sexes; the shaded area denotes the range of body weights found by Poiley with 90 to 100 animals at each age. The two thin curves represent older data, for comparison; the sexes have been combined for this figure.

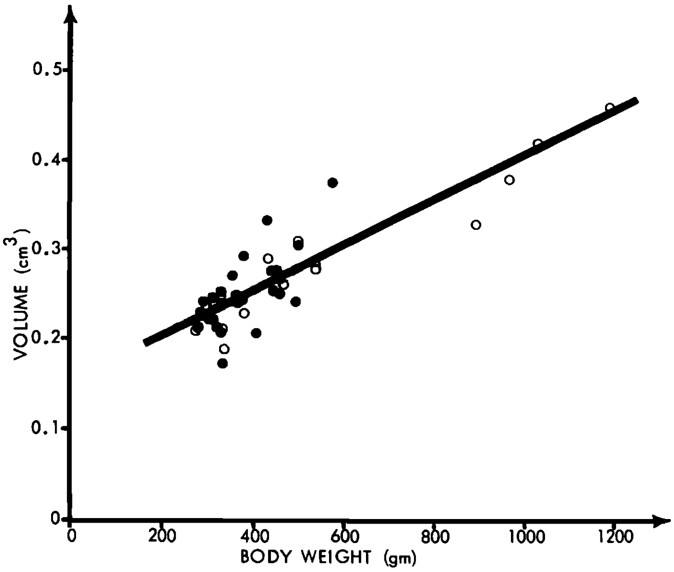

FIG. 2. Total middle-ear volume as a function of body weight. The total middle-ear volume is the sum of the tympanic and epitympanic volumes. The filled circles are data of Mundie (1971); the open circles are our data.

die's results are shown with filled circles, our own with open circles. A straight line has been fitted to the combined data. It is clear that there is, indeed, a strong relationship between middle-ear volume and body weight in the guinea pig; the regression line indicates a 50% volume increase over the range of 200 to 600 g. In fact, if one neglects the data above 600 g, the modified regression line indicates a volume increase of more than 75% over the same range of body weights.

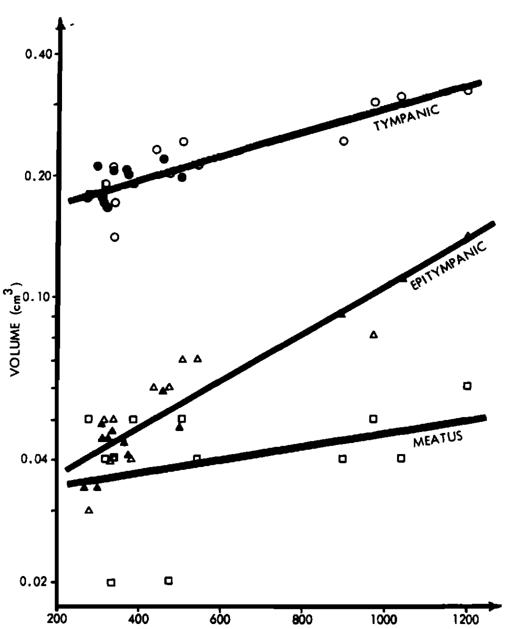

FIG. 3. Tympanic, epitympanic, and meatal volumes as functions of body weight. The filled symbols are data of Mundie (1971), the open symbols are our data.

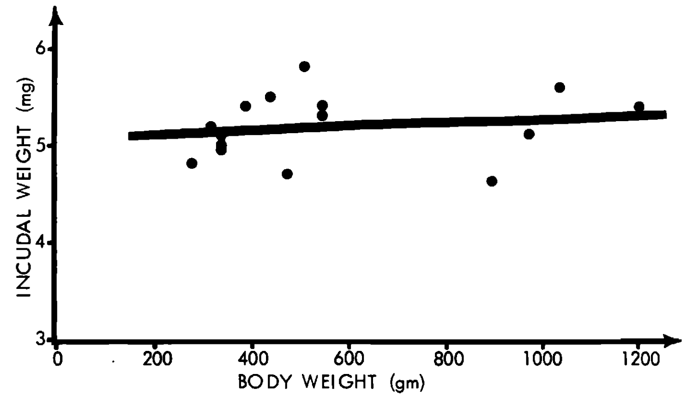

FIG. 4. Weight of the combined incus and malleal body, as a function of body weight.

We have also studied the relative sizes and growth rates of the individual cavities. The results are summarized in Fig. 3, which shows the volumes of the tympanic and epitympanic cavities, as well as the volume of the bony external auditory meatus, as functions of body weight. The volumes are plotted semi-logarithmically, so that the slopes of the fitted straight lines represent average specific growth rates. These rates are 0.57, 0.28, and 0.16 decades/kg for the epitympanic, tympanic, and meatal cavities, respectively. The growth rates for the tympanic and meatal cavities, which are both formed by the tympanic bone, are significantly lower ($p < 0.01$) than the rate for the epitympanic cavity, which is formed by the mastoid part of the petrosal bone.

In addition to the cavity volumes, another anatomical parameter of importance to middle-ear function is the mass of the ossicular chain. Figure 4 shows the dry weight of the combined incus and malleal body (which are completely fused in the guinea pig) plotted against body weight. The straight line shown is the least-squares fit and is practically horizontal, indicating that the incus and the body of the malleus do not continue to grow over this range of body weights. This does not prove that the eardrum, manubrium, and stapes have also stopped growing, but these account for only 10% to 20% of the mass of the ossicular chain according to the data of Mundie (1971) and so are relatively unimportant.

II. DISCUSSION

Middle-ear models in the literature, such as that of Zwislocki (1963) for the guinea pig, have generally used average or typical values for the various parameters involved. While such models provide valuable information about middle-ear function in general, their usefulness in interpreting the data from a particular subject is severely restricted because of the great variability between individuals. Nuechterlein and Pfeiffer (1970), for example, discuss the use of an electronic filter to compensate for the frequency characteristics of the middle ear of the cat, based on the model of Peake and Guinan (1967) which represents an "average" cat. The data that we have presented here suggest that a similar filter for the guinea pig would benefit from using the

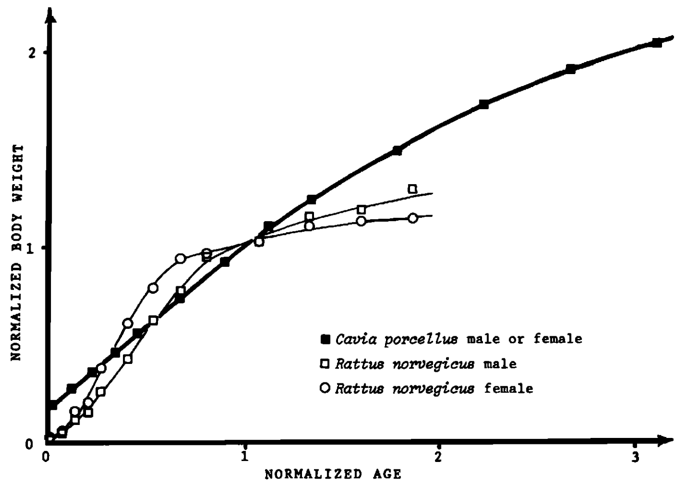

FIG. 5. Body weight as a function of age for the guinea pig (*Cavia porcellus*) and for the brown rat (*Rattus norvegicus*). To facilitate comparison, the curves are normalized, with the age and weight being divided by the age of sexual maturity, and by the corresponding body weight, respectively. Note that the rat grows relatively little after becoming adult, while the guinea pig continues to grow rapidly well after the breeding age. Although the female guinea pig is, on the average, lighter than the male, the curves for both sexes are the same shape. (Body-weight data are from Poiley, 1972; approximate ages of sexual maturity are from Walker *et al.*, 1968, p. 1017, and from Hall and Kelson, 1959, pp. 768–769.)

body weight to predict the values of certain model components, such as the cavity volumes. Other components, such as the mass of the incus, do not vary much with body weight and need not be modified. It should be noted that not all species continue to grow for as much of their lives as do guinea pigs. The rat, for instance, has more or less stopped growing by the age of sexual maturity (Fig. 5), so that body weight would not be a good predictor of middle-ear volume in adult animals.

Our data on the age dependence of the middle ear are also important to theoretical considerations of middle-ear function. In particular, the sizes of the two cavities and the form of the passage between them combine to cause a resonance and an antiresonance in the frequency characteristics of the middle ear, at least in the guinea pig (Mundie, 1962) and cat (Peake and Guinan, 1967). Any hypothesis concerning the possible functional importance of this resonance–antiresonance pair must certainly contend with the fact that the structures causing it vary considerably between individuals, and with age in the same individual. The way in which the resonance and antiresonance frequencies themselves vary will depend upon the interrelated variations of the cavity volumes and the acoustical inertance and resistance of the passage between the cavities.

The effects of middle-ear variations on middle-ear function probably deserve further study, especially with regard to the importance of the resonance as a survival characteristic. One must keep in mind, however, that the guinea pig is not an ideal species for research with evolutionary implications because its long period of domestication has made it very variable (Cockerell and Miller, 1914, p. 373), and one cannot assume that particular features really represent survival characteristics.

ACKNOWLEDGMENTS

We are very grateful to Dr. J. R. Mundie for providing us with his unpublished results. Dr. D. H. Moscovitch has been kind enough to review the manuscript critically. This work has been supported by the Medical Research Council of Canada.

Bessesen, A. N., and Carlson, H. A. (1923). "Postnatal growth in weight of the body and of the various organs in the guinea-pig," Am. J. Anat. 31, 483–521.

Cockerell, T. D. A., and Miller, L. I. (1914). "The auditory ossicles of American rodents. II. Families other than Arvicolidae and Muridae," Bull. Am. Mus. Nat. Hist. 33, 365–378.

Diamant, M. (1940). "Otitis and pneumatisation of the mastoid bone," Acta Otolaryngol. Suppl. 41, vii + 149 pp.

Funnell, W. R. J. (1972). "The acoustical impedance of the guinea-pig middle ear and the effects of the middle-ear muscles," Master's thesis, McGill University, Montreal, vi + 93 pp.

Funnell, W. R. J., and Laszlo, C. A. (1972). "The acoustical impedance of the guinea-pig middle ear and the effects of the middle-ear muscles," J. Acoust. Soc. Am. 52, 129(A) (1972).

Mundie, J. R. (1962). "The impedance of the ear—A variable quantity," USAMRL Rep. No. 576, 63–85.

Mundie, J. R. (1971). Personal communication.

Nuechterlein, P. E., and Pfeiffer, R. R. (1970). "Distortion-compensating filter for middle ear of the cat," IEEE Trans. BME-17, 72–73.

Peake, W. T., and Guinan, J. J., Jr. (1967). "A circuit model for the cat's middle ear," MIT Lab. Elect. QPR 84, 320–326.

Winge, H. (1888). "Fossil and living rodents (Rodentia) from Lagoa Santa, Minas Geraes, Brazil. With a review of the mutual relationships of rodents," E Museo Lundii Copenhagen 1, 1–200 (in Danish).

Zwislocki, J. J. (1963). "Analysis of the middle ear function. Part II. Guinea-pig ear," J. Acoust. Soc. Am. 35, 1034–1040.