The portrait given here has been photo-engraved from a photograph taken in 1864 by Heer's brother, kindly lent for the purpose by Professor Jules Marcou. The signature is taken from a letter addressed to the writer, under date of Aug. 13, 1883.

A HEARING OF BIRDS' EARS.[1]—III.

SECTION of bone is required for further examination of the ear parts. There being no mastoid affair to be considered as such, we may proceed directly to the 'petrous part of the temporal' (the periotic or petrosal bone); the otocrane, or otic capsule, enclosing the essential organ of audition just as the eyeball does that of vision, or the ethmoid bone that of olfaction. None of this bone is ordinarily recognizable on the outside of the skull; though in the embryo that part which is in especial relation with the posterior semicircular canal appears to a slight extent upon the occiput. The foundation of the bone is laid very early in cartilage; traces of the cochlea and canals being visible in the chick at the fifth day of incubation, if not sooner, in the primitive cartilaginous *basis cranii*, — the parachordal plate of cartilage on each side of the notochord. On longitudinally bisecting the adult skull, or otherwise gaining access to the brain-cavity, the whole cerebral surface of the petrosal bone is brought into view, as in fig. 4, *po*, *op*, *ep*. In a skull of any size, as that of an eagle (from which my description will be mainly derived), there is no difficulty in making out the parts, although the periphery of the petrosal is completely consolidated with surrounding bones. The petrosal or periotic bone consists of three distinct bones, which in some animals may remain long or permanently separate, or be consolidated with surrounding bones and not with one another. To see them it is usually necessary to examine a young skull, like that figured. These are the *pro-otic*, *po;* the *opisthotic*, *op;* the *epiotic*, *ep*. In the present case of the adult eagle, they are absolutely fused with one another, as well as with contiguous bones. The consolidated petrosal appears as an irregular protuberance upon the inner wall of the brain-cavity, much as the human petrous bone protrudes between posterior and middle cerebral fossae. It appears to be much more extensive than it really is, because the superior semicircular canal, too large to be accommodated in the petrosal, invades the occipital bone, — the track of the canal being sculptured in bas-relief, — as at *asc*, fig. 4. Behind this semicircular trace, the deep groove of a venous sinus (*sc*) is engraved upon the bone, throwing the track of the canal into still stronger relief. The top of the petrosal and contiguous occipital surface floors a fossa which lodges the enormous optic lobes (*corpora bigemina*) of the brain; in the eagle partly divided from the general cavity for the cerebral hemisphere by a bony tentorium, like that which in some mammals separates the cerebellar from the cerebral fossae. On the vertical face of the petrosal, or on the corresponding occipital surface, is a large smooth-lipped orifice leading to a tongue-like excavation which lodges the flocculus of the cerebellum, and would therefore seem to correspond to that slight chink of the human petrous bone, near the *meatus internus*, which lodges a process of the *dura mater*. In front, between the petrosal and the alisphenoid (or in the apposed border of one or the other of these bones), is a considerable foramen, — the exit of the second and third divisions of the trifacial (figs. 1 and 4, the hole marked *5*). Below the petrosal, between opisthotic and exoccipital, near the *foramen magnum*, is a foramen (which may be subdivided into foramina) representing the human *foramen lacerum posterius*, for transmission of the pneumogastric, etc. (fig. 4, the hole marked *8*). Thus, as always, the bony auditory capsule lies between the exits of the third division of the trifacial and the pneumogastric. The general space under description is continued to the margin of the *foramen magnum* by the exoccipital bone (fig. 4, *eo*). Now, on the vertical face of the petrosal itself, and in the pro-otic part, far behind the foramen marked *5* in fig. 4, considerably above that marked *8*, will be seen the large smooth-lipped orifice of the *meatus auditorius internus*, marked *7* in the figure. Here enter, as usual, both *portio dura* and *portio mollis* of the old seventh pair of cranial nerves. At the bottom of the meatus are at least two openings, small, but separate from each other. A bristle passed through the upper (anterior) one of these traces the course of *portio dura* (the facial nerve) through the fallopian aqueduct ('nerviduct,' it would be better called), and emerges in the tympanic cavity near the eustachian orifice. This orifice of exit of the facial is virtually a 'stylo-mastoid' foramen, though within the tympanic; for the nerve burrows through no more bone in reaching the surface of the skull. A bristle passed through the other one of the two foramina at the bottom of the meatus practically traces the course of the *portio mollis*, or auditory nerve,

[1] Concluded from No. 38.

and can also be made to come out into the tympanum, either through the vestibular or cochlear opening (*fenestra ovalis* or *fenestra rotunda*). In the dry skull, either passage is easily made without breaking down, and apparently without meeting any bony obstacle.

If, now, the whole periotic mass be cut away from the rest of the skull with a fine saw, and then divided in any direction, the bony labyrinth and essential organ of hearing can be studied. It is best to make the section in some definite plane with regard to the axes of the skull, — the vertical longitudinal, or vertical transverse, or horizontal, — as the disposition and relations of the contained structures are then more readily made out. Four or five parallel cuts will make as many thin flat slices of bone, affording eight or ten surfaces for examination. The whole course of the labyrinthine structures can be seen in sections, which, put together in the mind's eye, or held in hand a little apart, and visibly threaded with bristles, afford the required picture very nicely. At first sight, the unpractised eye will recognize nothing but confusion, — a bewildering maze of bone. All this cancellated structure or net-work, however, is pneumatic; the open-work tissue of bone containing air derived from the tympanum, and having nothing to do with the auditory cavities proper. Parts of the bony labyrinth will soon be recognized by their smooth, firm walls and definite courses, as distinguished from the irregular interstices of bone-tissue. They are, as usual, a central vestibular cavity, with its utricular recess; three semicircular canals; and the cochlear cavity, projecting downward like a beak (see figs. 5 and 6, the membranous labyrinth, to which the incasing bony cavities closely conform). According as the sections have been made, numerous cross-cuts of the canals will be seen here and there as circular orifices; the canals themselves lying curled like worms in the petrosal and occipital substance, their ends converging to the central vestibular cavity. As compared with those of man, the parts are of great size in a bird: in the eagle, for example, the whole affair is as large as the end of one's thumb, the whole length of the superior canal is an inch or more, and its calibre, I should judge, is absolutely about as great as in man. The cochlea, though not comparatively diminutive, is in an undeveloped state, as far as complexity of structure is concerned, — ligulate or strap-shaped, a little curved on itself, but making no whorl. This is substantially as in all Sauropsida (birds and reptiles), for the cochlea does not coil into a helix until we reach Mammalia. The tongue-like affair is simply as if a part of the first whorl of a mammal's cochlea very incompletely divided into *scala vestibuli* and *scala tympani* by cartilaginous structures representing a modiolus and its lamina, proceeding from the bony bar or bridge between *fenestra ovalis* and *fenestra rotunda*. These are the external (*a*) and in-

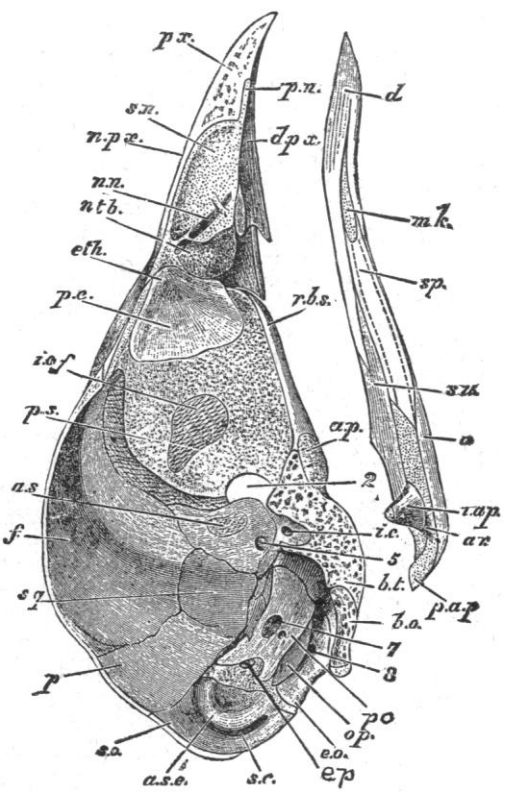
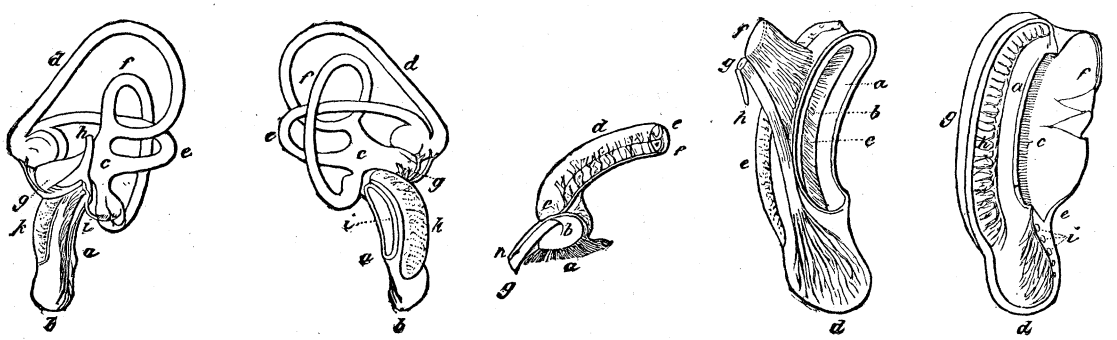


FIG. 4. — Ripe chick's skull, longitudinal section, viewed *inside*, × 3 diameters. (After Parker.) In the mandible are seen, — *mk*, remains of meckelian rod; *d*, dentary bone; *sp*, splenial; *a*, angular; *su*, surangular; *ar*, articular; *iap*, internal articular process; *pap*, posterior articular process: in the skull, — *pn*, the original prenasal cartilage, upon which is moulded the premaxillary, *px*, with its nasal process, *npx*, and dentary process, *dpx*; *sn*, septo-nasal cartilage, in which is seen *nn*, nasal nerve; *ntb*, nasal turbinal; *eth*, ethmoid; *pe*, perpendicular plate of ethmoid; *iof*, inter-orbital foramen: *ps*, presphenoidal region; *2*, *optic foramen*; *as*, alisphenoid, with *5*, foramen for divisions of the fifth nerve; *f*, frontal; *p*, parietal; *so*, super-occipital; *asc*, superior semicircular canal; *sc*, a sinus (venous) canal; *ep*, epiotic; *eo*, exoccipital; *op*, opisthotic; *po*, pro-otic, with *7*, *meatus auditorius internus*, for entrance of seventh nerve; *8*, foramen for vagus nerve; *bo*, basi-occipital; *bt*, basi-temporal; *ic*, canal by which carotid artery enters brain-cavity; *ap*, basi-pterygoid process; *ap* to *rbs*, rostrum of the skull, being the parasphenoid bone underflooring the basi-sphenoid and future perpendicular plate of ethmoid.

ternal (*b*) cartilaginous prisms shown in figs. 8 and 9. The cochlea ends with a saccular part, termed the 'lagena.' Details of the soft parts — membranous, vascular, and nervous — will readily be made out from Professor Ibsen's beautiful figures, here reproduced (figs. 5, 6, 8, 9), with ample explanatory text.

The vestibule hardly requires special description, after examination of figs. 5 and 6. In the eagle, if its irregularities of contour were smoothed out, it would about hold a pea. Its utricular recess (*g*) is well developed.

In the language of human anatomy, the three semicircular canals are the anterior or superior vertical, the posterior or inferior vertical, and the external or horizontal; and the planes of their respective loops are approximately perpendicular to one another in the tal one, *e*, which tilts down backward. The verticality of the planes of *d* and *f* is preserved. The canals in birds might be better known as the superior (*d*) and inferior (*f*) vertical, and horizontal (*e*); though it is not probable, viewing the great variation in the axes of this part of the skull, that any terms descriptive of *direction* will apply perfectly to all birds. Whatever its inclination backward, there is no mistaking *d*, which is much the longest of the three, looping high over the rest, exceeding the petrosal, and partly bedded in the occipital, with the upper limb bas-relieved upon the inner surface of the skull (fig. 4, *asc*). The one marked *f* loops lowest of all, though little, if any of it, reaches farther back than *d;* it is the second in size, and quite circular (rather more than a semicircle). Its upper limb joins



FIGS. 5, 6. — Membranous labyrinth of *Haliaetus albicilla*, × 2. *a*, *b*, cochlea; *b*, its saccular extremity (or lagena); *c*, vestibule; *g*, its utricle; *d*, anterior or superior vertical semicircular canal; *e*, external or horizontal semicircular canal; *f*, posterior or inferior vertical semicircular canal; *h*, membranous canal leading into aqueduct of the vestibule; *k*, vascular membrane covering the *scala vestibuli*. Opposite this, at *i*, are seen the edges of the cartilaginous prisms in the *fenestra rotunda:* from the edges of these cartilages proceeds the delicate membrane closing the opening of the cochlea (not shown in the figure).

FIG. 7. — Part of the superior vertical semicircular canal, showing its ampulla, nerve of ampulla, artery, and connective tissue of the perilymph, × 3. *a*, that part of the vestibule (alveus) next to the ampulla; *b*, the dilatation of the ampulla at its vestibular opening; *c*, where it passes into the canal proper; *d*, the canal, furnished with connective tissue of the perilymph along its concave border and sides, as appears clearly at the sections *e* and *f; g*, nerve of the ampulla; *h*, artery of the connective tissue, running beneath it, remote from the wall of the duct.

FIG. 8. — Cochlea, × 3. *a*, external, *b*, internal, cartilaginous prism; *c*, membranous zone; *d*, saccular extremity of the cochlea, or lagena; *e*, vascular membrane; *f*, auditory nerve, its middle fascicle penetrating the internal cartilaginous prism, to reach the membranous zone by its terminal filaments; *g*, auditory nerve, its posterior fascicle running to the most posterior part of the lagena; *h*, filament to ampulla of posterior or inferior vertical semicircular canal.

FIG. 9. — Section of the cochlea. *a*, vestibular surface of external cartilaginous prism, extending into *d*, the lagena; *c*, section of the membranous zone; *e*, Huschke's process of the fenestra, which, with the margins of the cartilaginous prisms, affords attachment to the blind sac, *f*, occluding the fenestra of the cochlea; *g*, spongy vascular membrane of the *scala vestibuli; h*, auditory lamellae of Treviranus; *i*, canals in posterior wall of the lagena, by which the nervous filaments enter its cavity.

(From Ibsen's Anatomiske undersögelser over örets labyrinth. Kjöbenhavn, 1881, p. 17, pl. 1, figs. 13–17.)

three planes of any cubical figure. In birds, these terms do not apply so well to the situation of the canals with reference to the axes of the body, nor to the direction of their loops; neither is their mutual perpendicularity so nearly exhibited. The whole set is tilted over backward to some extent, so that the anterior (though still superior) canal, *d*, in figs. 5 and 6, loops back beyond either of the others; its anterior limb is also straightened out. The posterior (though still inferior) canal, *f*, loops behind and below the horizon- the lower limb of *d* as in man, and the two open by one orifice in the vestibule; but, as far as the bony tubes are concerned, it is not simple union, for the two limbs, before forming a common tube, twine half around each other (like two fingers of one hand crossed). The loop of *f* reaches very near the back of the skull (outside). The horizontal canal, *e*, is the smallest, and, as it were, set within the loop of *f;* its plane, the opposite of that of *f*. The bony cavities of *e* and *f* intercommunicate where they cross, at or near the point of their

greatest convexity, farthest away from the vestibule. This decussation of *e* and *f*, like the twining inosculation of *f* and *d*, is well known. It may not be so generally understood that there is (in the eagle; I do not know whether or not in birds generally) a *third* extra-vestibular communication of the bony canals. My sections show this perfectly. The great loop of *d*, sweeping past the decussation of *e* and *f*, is thrown into a cavity common to all three. Bristles threaded through each of the three canals can all be seen in contact, crossing one another through this curious extra-vestibular chamber. I call it the *trivia*, or 'three-way place.' It is just where, in fig. 6, the three membranous canals decussate, — midway between the letters *e*, *f*, and *c*. It does not, of course, follow, that the contained membranous canals intercommunicate here, and it appears from Ibsen's figures that they do not. The ampullar dilatations of the ends of the canals are well marked. The anatomy of associate soft parts is explained to some extent under fig. 7.

The endolymph may contain otoliths similar to those great concretions called 'ear-stones' in fishes. The equilibrating function of the labyrinth and its fluid appears to have been determined mainly from experiments upon birds. The apparatus may be likened to the glass tubes filled with water and a bubble of air, by a combination of which a surveyor, for example, is enabled to adjust his theodolite true; for a bird somehow knows how the liquid stands in these self-registering levelling tubes, and adjusts itself accordingly. Observations made upon pigeons show, that, "when the membranous canals are divided, very remarkable disturbances of equilibrium ensue, which vary in character according to the seat of the lesion. When the horizontal canals are divided, rapid movements of the head from side to side in a horizontal plane take place, along with oscillation of the eyeballs, and the animal tends to spin round on a vertical axis. When the posterior or inferior vertical canals are divided, the head is moved rapidly backwards and forwards, and the animal tends to execute a backward somersault, head over heels. When the superior vertical canals are divided, the head is moved rapidly forwards and backwards, and the animal tends to execute a forward somersault, heels over head. Combined section of the various canals causes the most bizarre contortions of the head and body." — (Ferrier, *Funct. of the brain*, 1876, p. 57.) Injury of the canals does not cause loss of hearing, nor does loss of equilibrium follow destruction of the cochlea. Two diverse though intimately connected functions are thus presided over by the acoustic nerve, — audition and equilibration.

The wonderful and endlessly varied songs of birds may acquire for us a new significance, now that we understand the mechanism by which these engaging creatures derive pleasure from their own music. Though no two things can well be conceived more different than an anatomical disquisition and a bird-song, either may be made to subserve the purpose of a truer appreciation of the other; and there may be physiological aspects of even a 'Christmas carol.' ELLIOTT COUES.

Washington, Christmas, 1882.

WHIRLWINDS, CYCLONES, AND TORNADOES.[1] — I.

THE general circulation of the winds is at times interrupted by local and temporary disturbances of very varied size and strength, to which the general name of 'storms' is given. Their most constant features are, a more or less pronounced inward spiral whirling of the air near the ground, feeding an up-draught at the centre, and an outflow above; and a progressive motion from place to place, along a tolerably well-defined track. Clouds, and generally rain as well, accompany the larger storms.

It is our object to explain how these disturbances arise, to examine the causes and methods of their peculiar action, and to study their distribution in time and place. With this end in view, the small dust-whirlwinds that commonly arise in the hot dry air of deserts will be first considered. Next will come the great hurricanes and typhoons of the tropical seas, and the less violent rotary storms of our own latitudes, all of which may be grouped together as cyclones. The tornadoes and water-spouts, showing a peculiar concentration of power over a very limited area, will be discussed last.

The dry whirlwinds in flat desert regions suddenly interrupt the calmness of the air, and begin turning, catching up dust and sand, and carrying them upwards through the spiral vortex to a height of many hundred feet. They are therefore not at all like those whirls formed about our street-corners at the meeting of opposing currents of blustering wind, or the eddies of greater strength seen in windy mountain regions; for they arise in a time of quiet, and begin their motion without apparent cause. Hence we must, at the outset, inquire into the

[1] Based on a series of lectures delivered at the Lowell Institute, Boston, in January, 1883.