AN APPARATUS FOR MEASURING KINETICS IN AVIAN SKULLS

BY HARVEY I. FISHER AND DONALD C. GOODMAN

IN 1867 Huxley distinguished several basic types of construction in the ventral parts of birds' skulls. The structure of these types is in part responsible for the degree of movement (kinetics) at the frontonasal hinge. Despite this early recognition of the mechanism and the possibility of movement, the concept of kinetics here was not extensively explored until the work of Moller (1931), Kripp (1933-1935), and especially Engels (1940). Hofer (1945) dealt with the problem in a functional and quantitative way. Beecher (1951*a*) carried this approach farther. Additional work by Hofer (1950), Beecher (1950, 1951*b*, 1953) and Fiedler (1951) has shown the importance of kinetics, as part of the functional jaw mechanism, in long-term adaptive changes of evolutionary significance.

The studies cited above have, for the most part, been subjective and qualitative. This has caused some concern in our laboratory. We could not find in the literature any measure of the accuracy of judging the degree of kinetics in the skull of a species or any evidence of statistical reliability and variation within a species. Where the kinetic attributes of two different species have been compared, there were no statistical data to support hypotheses of significant or insignificant differences between the two. It would seem that the criteria of variation, reliability, and significance must be established before it is possible to interpret the kinetics in terms of function or adaptive significance.

We failed to see how accurate quantitative data could be obtained following the methods of observation employed by the authors listed. We could find no description of any apparatus that would produce consistent and accurate measurements which could be compared from species to species. This statement is not to be construed as a criticism of these workers; several were interested only in the qualitative, and those who gave quantitative data generally used them as approximations only.

An apparatus was designed to produce quantitative data on this problem and to eliminate, as far as possible, the subjective aspects of past work. This equipment is illustrated in Figure 1.

DESCRIPTION OF THE APPARATUS

The machine is constructed of brass. Therefore the apparatus is sturdy but not great in weight, enabling easy transport to and from the field. This light weight makes necessary the use of a C-clamp (not illustrated) to secure the apparatus to the edge of a table or desk during use.

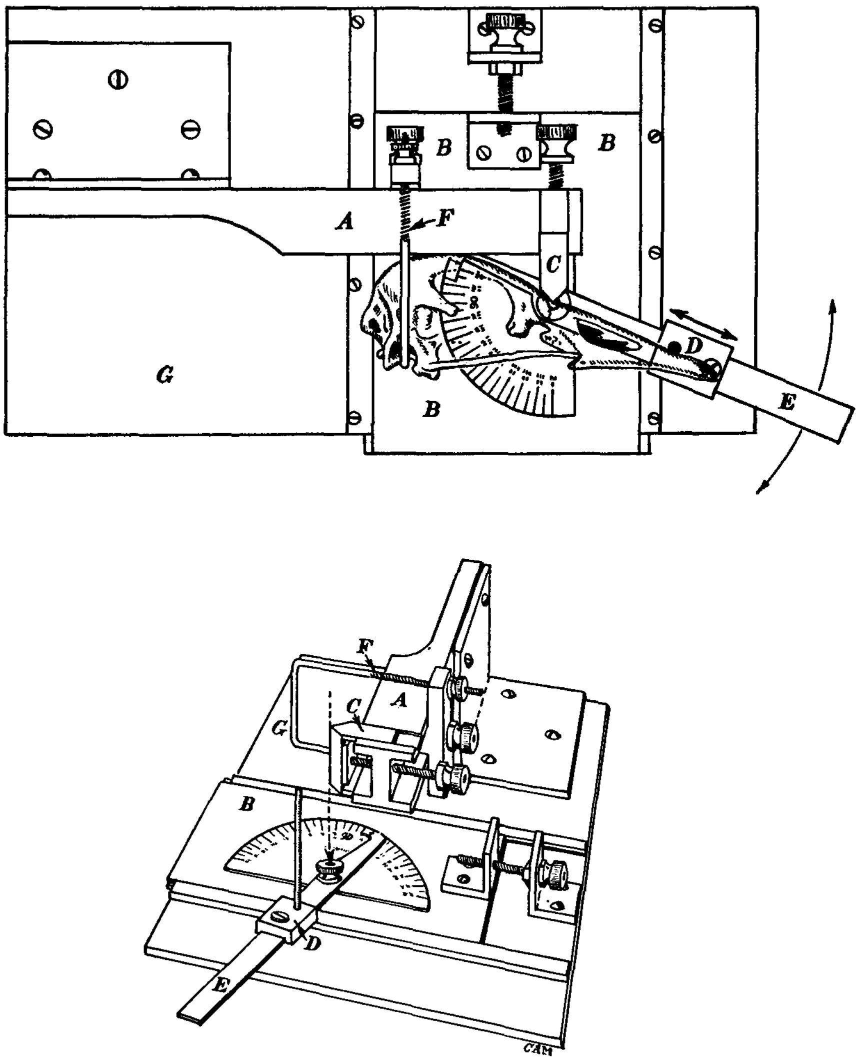

FIG. 1. An apparatus for measuring the kinetics in the frontonasal hinge of the avian skull. Upper figure: top view. Lower figure: oblique end view. See text for details of operation.

Beam A is elevated from base plate G by a wide L-bar. The part of beam A which is free of attachment to the L-bar has been machined into an I-beam. The purpose of the I-construction is to make possible the fixing of clamp F at any point along the length of beam A. It also provides a rest for the convex dorsal surface of the cranium. The edges of the I provide a sturdy contact for the curved cranial surfaces and eliminate dorso-ventral rocking.

The adjustable knife edge C is located at the free end of beam A. By means of a screw, threaded through the beam, the knife edge may be moved closer to or farther from the beam, accommodating high- or low-vaulted skulls. The base of the knife edge slides in grooves on the upper and lower surfaces of beam A, thereby maintaining the knife edge perpendicular to the axis of the beam. The knife blade is of a length that the entire width of the frontonasal hinge will rest on it. This eliminates dorso-ventral rocking and allows equal distribution of force at the pivot of the system.

The base of clamp F which fits into the posterior depression of the I-beam provides strong and uniform attachment to the beam. Both ends of the rod portion of the clamp are threaded and fitted with thumb nuts. The nuts are tightened for coarse adjustment of the sides of the clamp, but a set-screw threaded into the base of the clamp provides the fine adjustment. The set-screw draws the entire clamp tight against the I-beam.

A protractor of 180 degrees is soldered to a sheet of brass—the sliding protractor plae B. The protractor plate is held to base plate G and is guided in its movement, which is perpendicular to the axis of the beam, by grooved guide bars attached to the base plate. The exact movement of the protractor plate is accomplished by the set-screw shown at the top of the drawing. This adjustment is necessary to insure that the center point of the protractor is directly below the knife edge.

The protractor arm E is fitted with an adjustable vertical extension D. The vertical extension is clamped to the protractor arm. The extension arm may be moved along the length of the protractor arm to adapt for bills of different lengths.

Certain principles in the construction and use of this apparatus merit brief mention. Only two subjective aspects remain. The scale must be read and the hand must be used to manipulate the upper bill. The error in reading the scale is minor; the calibration is in full degrees and so is the reading. The force used to press the tip of the bill upward is a thumb or finger. This pressure might be considered an inconsistently variable feature, but several factors reduce the possible error. With repetition, the user becomes accustomed to the amounts of pressure to be used with the skulls of different species. Then too, in all the species we have thus far dissected, there are ligaments which limit upward motion in the bill. As the bill is pushed upward there is a sudden stop when the ligament is fully extended. We have found, in those forms possessing a basipterygoid process, that the movement between the articular surfaces of this process and of the pterygoid is limited to approximately one-half the length of the articular surfaces. That is, if the two surfaces are opposite each other when the upper bill is retracted, only half their lengths will be articulating when the ligament halts the movement. Thus, if this fact has been determined for a species, the skull prepared in the usual way for museums may be used. Pressure is exerted on the tip of the upper jaw until the articular surfaces are in the proper position.

A second important feature of the apparatus is its rigidity. All parts are firmly attached, and the bird's head or skull is clamped tightly. The frontonasal hinge, knife edge, and center of arc of protractor are strictly aligned. The clamp and the length of the knife edge prevent any rolling of the skull.

Deflection of the protractor results from pressure on the vertical, fixed arm. No subjective sighting from point to point is necessary.

Parts of the apparatus adjustable for heads and skulls of different sizes are as follows:

1. beam (A)—inserts with smaller grooves may be used for measuring small skulls.
2. knife edge (C).
3. clamp (F)—different lengths and shapes.
4. sliding protractor plate (B).
5. sliding vertical arm (D) on protractor arm (E).

Use of the Machine

1. Adjust the holding-rod of the clamp to grasp the skull immediately anterior to the opisthotic processes. In this position the skull may be held firmly without interference with movable bones.

2. Move the clamp and skull to make the knife edge and frontonasal hinge adjacent.

3. Adjust the knife edge so that when the frontonasal hinge contacts the knife edge the ventral edge of the skull is approximately parallel to the edge of the base plate.

4. Move the protractor center-point by moving plate B so that the center of the protractor arc is aligned with the knife edge. (The skull is tipped forward so that this alignment can be made.)

5. Move the frontonasal hinge into position against the knife edge and adjust the skull in the clamp by use of the set-screw. The correct seating of the skull in the I-beam should be checked; the final adjustment of the clamp must hold the skull tightly.

6. Move the vertical extension arm along the protractor arm so that the extension will conveniently meet the dorsal edge of the upper bill. Use of any point on the bill will produce the same angle, but we chose for the area of contact a point in the distal one-fourth of the bill length.

7. Move the protractor arm so that the vertical extension touches the dor-

sal surface of the bill. The number of degrees indicated on the protractor is the zero reading.

8. Force is applied with a thumb or finger on the ventral surface of the tip of the upper bill until resistance is met. When the orbito-pterygo-palatal ligament is in place, this point of resistance is very definite. A second reading of the protractor is made.

9. The final protractor reading minus the zero reading is the number of degrees that the upper bill has moved.

In the long series of skulls that have been measured in this and other unpublished work, it was found that sufficient accuracy could be obtained by holding the skull in place in the apparatus with a thumb on the basisphenoid plate and fingers grasping the I-beam. This elimination of the adjustment of the clamp permitted more speed in the use of the machine.

Reliability

One of the most important features in the use of any apparatus is constancy in results obtained. That is, what is the error in continuous or discontinuous use when all factors are equal? To test this, one of us measured the kinetics in the head of one Canada Goose, *Branta canadensis interior*, on different days within a period of one month. The head was preserved in embalming fluid with ligaments intact, but the muscles were removed. The head was removed from the apparatus and replaced before each test. The data from this series follow:

Number of trials=66
Mean=17.7 ± .11 degrees
Standard deviation=0.86 degrees
Observed range=16—19 degrees
Theoretical range (M ± 3 standard deviations)=15.1—20.3 degrees
Coefficient of variation=4.9

This information indicates that the mean would lie between 17.4 and 18.0 in 99 of every 100 measurements, no matter how many tests were made. This would be an error of about 3.5% of the minimal mean or, calculated as a part of the observed mean, an error of less than 2% on either side of the observed mean. The error here is that of the machine and its single user.

For the apparatus to be of universal practicability the results should be duplicable by different workers. In a test of this, each of us, independently, measured the kinetics in the same head of a Canada Goose. The head was in the same state of preservation as the head in the first test. The head used in the first test was not used here because we thought there might be some loosening of articulations and stretching of ligaments with prolonged use of materials hardened in a preservative. The data of the second test follow:

	Observer 1	*Observer 2*
Number of trials	51	51
Mean in degrees	16.0±.16	15.5±.16
Standard deviation	1.17	1.16
Observed range	14–19	13–18
Theoretical range	12.5–19.5	12.0–19.0
Coefficient of variation	7.3	7.5

In each of these series the error on either side of the mean is about 3%. However, the important point here is that the variation between the means of the two series is only 3%. This indicates that different workers can use the machine and obtain comparable results.

Summary

An apparatus was designed to measure the degree of movement (kinetics) in the frontonasal hinge of the avian skull. Several tests demonstrated that the device produced reliable and consistent figures when operated over a period of time by one observer or when used by two different workers.

Literature Cited

Beecher, William J.
1950 Convergent evolution in the American orioles. *Wilson Bull.*, 62:51–86.
1951*a* Adaptations for food-getting in the American blackbirds. *Auk*, 68:411–440.
1951*b* Convergence in the Coerebidae. *Wilson Bull.*, 63:274–287.
1953 A phylogeny of the oscines. *Auk*, 70:270–333.

Engels, William L.
1940 Structural adaptations in thrashers (Mimidae: genus Toxostoma) with comments on interspecific relationships. *Univ. Calif. Publ. Zool.*, 42(7):341–400, 24 figs., 11 tables.

Fiedler, Walter
1951 Beiträge zur Morphologie der Kiefermuskulatur der Oscines. *Zool. Jahrb.* (Anatomie), 71(2):145–288, 25 figs.

Hofer, Helmut
1945 Untersuchungen über den Bau des Vogelschädels, besonders über den der Spechte und Steisshühner. *Zool. Jahrb.* (Anatomie), 69(1):1–158, 30 figs.
1950 Zur Morphologie der Kiefermuskulatur der Vögel. *Zool. Jahrb.* (Anatomie), 70(4):427–600, 44 figs.

Huxley, Thomas H.
1867 On the classification of birds; and on the taxonomic value of the modifications of certain of the cranial bones observable in that class. *Proc. Zool. Soc. London,* 1867:415–472, 36 figs.

KRIPP, DOMINIK V.
1933*a* Der Oberschnabel-Mechanismus der Vögel (Nach den Methoden der graphischen Statik bearbeitet.) *Morph. Jahrb.*, 71:469–544, 45 figs.
1933*b* Die Spezialisationsreiche der Störche, Reiher und Kormorane vom konstruktiven und biotechnischen Standpunkt. *Morph. Jahrb.*, 72:60-92, 22 figs.
1933*c* Beiträge zur mechanischen Analyse des Schnabelmechanismus. *Morph. Jahrb.*, 72:541–566, 11 figs.
1935 Die mechanische Analyse der Schnabelkrümmung und ihre Bedeutung für die Anpassungsforschung. *Morph. Jahrb.*, 76:448–494, 23 figs., 10 tables.

MOLLER, WALTER
1931 Über die Schnabel- und Zungenmechanik blütenbesuchender Vogel. Ein Beitrag zur Biologie des Blumenvogels II. *Biol Generalis*, 7:99–154, 20 text-figs. 2 pls.

DEPARTMENT OF ZOOLOGY, UNIVERSITY OF ILLINOIS, URBANA, ILLINOIS, MARCH 7, 1954