A COMPARATIVE STUDY OF THE MECHANICS OF FLYING AND SWIMMING IN SOME COMMON BROWN BATS

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Although bats made their appearance upon the earth more than a million years ago, the first known reports of North American bats having the ability to swim were reported by Craft and Dexter (1955) and Patten and Patten (1956). The data reported here attempt to give comparative measurements of some of the anatomical mechanics involved in flying and swimming in *Myotis sodalis* and *Eptesicus fuscus*. It is also apparent that this situation presents an excellent opportunity to compare some of the physiological differentials of an animal performing a function for which it is accustomed and primarily adapted, with one for which it is neither accustomed to performing nor primarily adapted. A comparative study of some physiological stresses evidenced during flying and swimming in bats is currently under study in our laboratory.

MATERIALS AND METHODS

The *Myotis sodalis* used in this investigation were collected from Carter Caves located in northeastern Kentucky. Seventeen specimens were collected January 6, 1956, and thirteen specimens were collected March 25, 1956. Twenty-three specimens of *Eptesicus fuscus* were collected from a stock barn in Greene County, Ohio during October 1956. It was standard procedure to determine the sex, weight, body length (snout to vent) and the forearm length of each animal. The animals were not fed during the tour of investigation. The bats were stored at 4±2°C. One hour prior to any given test the specimens to be tested were removed from the temperature of 4±2°C to one of 22±2°C. Burbank and Young (1934), Evans (1938), and Hock (1951) have agreed that the body temperature of bats remains within one or two degrees centigrade of the atmospheric temperature when the bat is inactive. We found sixty minutes to be sufficient time for the temperature to change from one of approximately 4 to 6°C to one of 22 to 24°C. We also found 22°C to be sufficient temperature to allow normal flight by the bats tested. However, Larsell and Dow (1935), as a result of observations made on a *Corynorhinus* sp., listed four stages of emerging from winter sleep, namely:

(1) when the temperature is below 0°C, rigidity is evidenced. Only the grasping reflex of the hindfeet is slightly evidenced.
(2) stage of medula reflexes, grasping reflex is fully exhibited. (atmospheric temperature above 0°C).
(3) at approximately 10°C, marks the beginning of cerebral activity and protective movements are evidenced.
(4) at approximately 35°C, marks the stage of awakening, all muscular activities are regained.

The bats were allowed to fly in a laboratory 10 x 7 x 3.3 m. They were allowed to swim in a tank 1.5 x 1 m containing approximately 6 ft^3 of tap water. The animals performed the operations of flying and swimming on different days. Observations on the mechanics of flying and swimming were made by motion picture photography. Pictures were taken at sixty-four frames per second.

RESULTS AND DISCUSSION

In the collections of *M. sodalis* sixty-three percent were male and thirty-seven percent were female. The collections of *E. fuscus* contained sixty-nine percent

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male specimens and thirty-one percent female. The results of the observations made on their capacities to fly and swim have been tabulated in table 1.

Eisentraut (1936) showed in a set of motion picture figures that a large mouse-eared bat found in Germany made eleven or twelve wing beats (flying stroke cycles) per second while flying and in this time traveled about 420 cm. The flying and swimming stroke cycles are divided into a propulsion phase, which is responsible for the animals forward movement, and a recovery phase. The duration of the flying stroke cycle was observed to be the same in *M. sodalis* and *E. fuscus*, this being 0.109 second in each group. The propulsion phase required 0.062 second for its completion while the duration of the recovery phase was 0.047 second. There was a difference in the rate of execution of the swimming stroke cycle between the *M. sodalis* and *E. fuscus*. The pattern of the swimming stroke cycle was the reverse of the flying stroke cycle in that the recovery phase was 0.016 second longer than the propulsion phase. In *M. sodalis* the swimming stroke cycle lasted 0.172 second (fig. 1 to 11). The propulsion and recovery phases lasted 0.078 and 0.094 second, respectively. In *E. fuscus* the swimming stroke cycle lasted 0.203 second; the duration of the propulsion phase was 0.094 second, and the duration of the recovery phase was 0.109 second.

TABLE 1

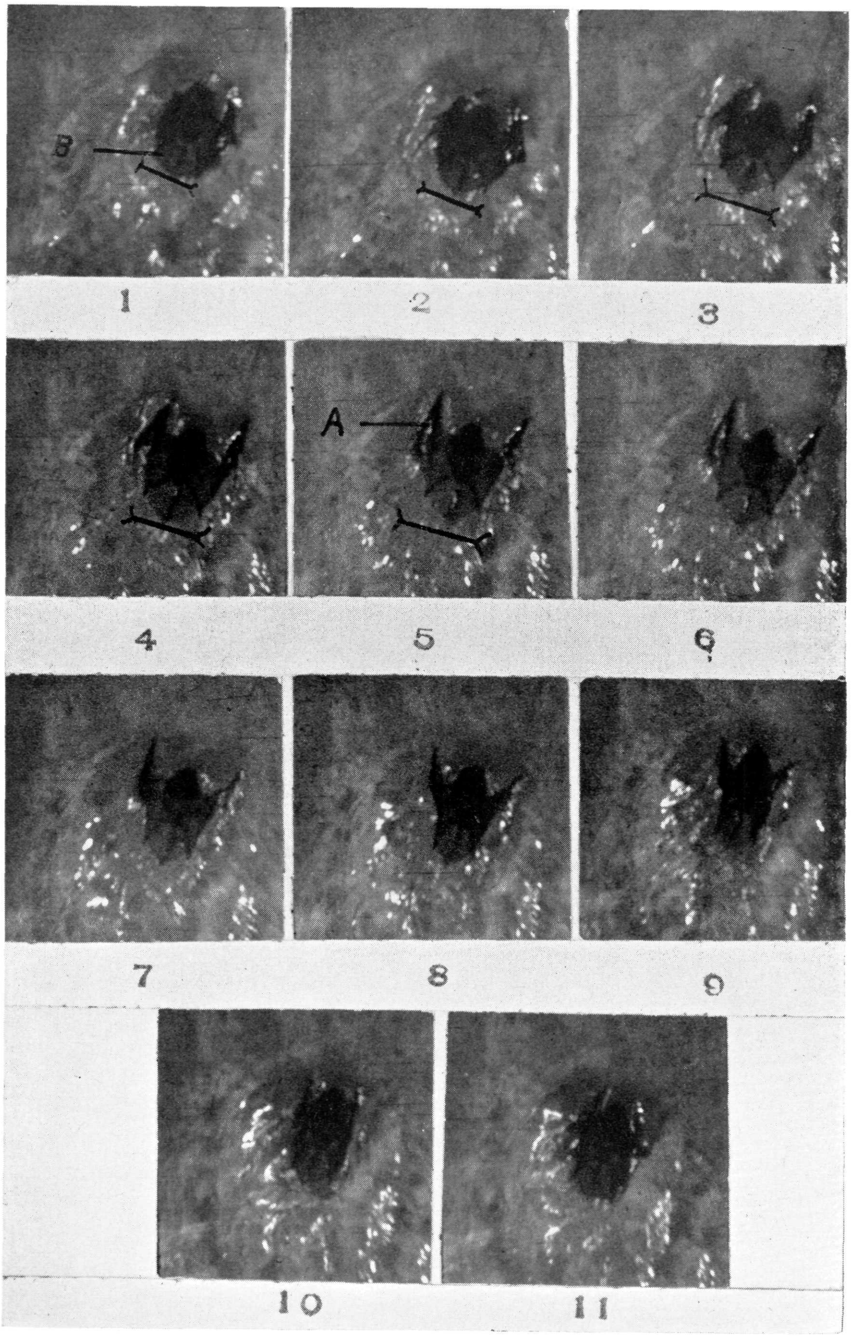
Flying and swimming in bats

Average Data	Number of observations	*M. sodalis*	Number of observations	*E. fuscus*
Weight	29	8.8 gm	23	21.75 gm
Combined length of head and body	29	81.9 mm	23	106.85 mm
Length of forearm	29	39.4 mm	23	46.8 mm
Rate of flying	15	2,986 mm/sec	18	3,671 mm/sec
Wing beats	15	9.1 /sec	18	9.1/ sec
Distance/wing beat	15	328 mm	18	403 mm
Rate of swimming	25	295 mm/sec	21	308 mm/sec
Wing beats	25	5.8 /sec	21	4.9 /sec
Distance/wing beat	25	53 mm	21	61 mm

During the swimming propulsion phase (fig. 1 to 5), the lateral extension of the uropatagium (fig. 1, B) increased as the wing unfolded latero-posteriad. The lateral extension of the uropatagium decreased during the recovery phase (fig. 6 to 11) and at this time the anterior appendages moved dorso-medio-anteriad. In *M. sodalis*, the distance traversed by the distal extremity of one forearm during a single swimming stroke cycle was equal to 88 percent of the body length. In *E. fuscus*, the distance traversed by the distal extremity of one forearm during a single swimming stroke cycle was equal to 87 percent of the body length.

During flight the tip of the uropatagium was curved ventrad thereby producing a dorsal arch on the body of the uropatagium. Such a position enabled the uropataguim to serve as a rudder. When the bat was swimming, the tip of the uropatagium was curved dorsad which produced a ventral arch in the body of the uropatagium (fig. 1 to 11). This position reduced the resistance of the water upon the forward movement of the bats's body as well as increasing the buoyancy effect upon its body. The ventral arch was deeper in the best swimmers. Without sufficiently ventral arched uropatagium the caudal end of the animal had a tendency to become submerged in the water at which time the animal began to flounder.

The bats tested did not swim with equal facility. Velocity was selected as a



The photographs were taken with a Bolex 35 mm motion picture camera at sixty-four frames per second. *Myotis sodalis* completing the cycle of a swimming stroke.

1 to 5 show the propulsion phase of the swimming stroke cycle.

A—wing B—uropatagium

6 to 11 show the recovery phase of the swimming stroke cycle.

basis for evaluation of the bats capacity to fly and swim. Three classifications of the ability to fly and swim were arbitrarily established as shown in table 2. In both species of bats tested, the style of swimming closely resembled the butterfly stroke employed by human swimmers. While both species resembled the butterfly stroke, the movements of *E. fuscus* resembled this style of swimming more closely than did those of *M. sodalis*. The forearms served as rudders during swimming. Both species were able to float without apparent difficulty. When floating, the wings were folded alongside the body; the uropatagium remained arched ventrad.

Upon comparing the distance traveled per wing beat to length of body, we found that based on the average rates of all members of *M. sodalis* tested, they flew 4 times the length of their body per stroke and swam 0.64 of their body length per stroke cycle. The members of *M. sodalis*, classified as good flyers, traveled a distance equal to 4.7 times their body length and those classified as good swimmers swam a distance equal to 0.98 of their body length. Based on the average rates of all members of *E. fuscus* tested, they flew 3.8 times their body length per stroke cycle and swam 0.57 of their body length. The members of *E. fuscus* classified as good flyers flew 4.4 times their body length. A good swimmer of the human species is expected to propel himself a distance equal to the length of his body per stroke cycle.

TABLE 2

Classification of swimming and flying in bats

Genera	Operation	mm/sec	Rating	% of animals in classification
Myotis	Flying	3,360–4,540	Good	22
		2,210–3,350	Average	66
		1,320–2,200	Poor	12
	Swimming	400–520	Good	30
		220–390	Average	46
		100–210	Poor	24
Eptesicus	Flying	3,360–4,540	Good	69
		2,210–3,350	Average	16
		1,320–2,200	Poor	15
	Swimming	400–520	Good	21
		220–390	Average	53
		100–210	Poor	26

The bats did not improve their rates of swimming with practice. Those classified as good swimmers swam readily and did not flounder about the sides of the tank. Instead they swam on a straight course, with strong, graceful strokes, and with a deep ventral arch in their uropatagium. The hair of the good swimmers did not wet as easily as did the hair of the animals falling into other classifications. Apparently the sebaceous glands secreted a more resistant coating of oil onto the root sheath of the hair. This is in keeping with observations that have been made on aquatic birds. If the feathers of aquatic birds are not adequately preened, the birds fail in their attempts to swim. The weight and body length of the bats did not have a direct effect upon the rate at which they flew or swam.

It was observed in both species that females swam faster than males and that they had shorter forearms. The data in table 2 show that 50 percent of all animals tested flew and swam equally well: 33 percent flew better than they swam; and 16 percent swam better than they flew.

SUMMARY

1. Animals classified as good swimmers evidenced a deeper ventral arch in their uropatagium.
2. The hair of animals classified as good swimmers wetted less easily than the hair of those bats falling into other classifications.
3. Females of *Myosis sodalis* and *Eptesicus fuscus* swam faster than the males of the respective species.
4. The females of each species had an average forearm length that was shorter than that of the males in their species.
5. There was no apparent direct effect of body length and weight upon the bat's rate of flying and swimming.
6. The recovery phase of the flying stroke cycle of both species was 0.016 second shorter than the propulsion phase, but was 0.016 second longer than the propulsion phase during the swimming stroke cycle.
7. (a) According to our classification, 50 percent of all animals swam and flew equally well; (b) 33 percent flew better than they swam; and (c) 16 percent swam better than they flew.

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