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## Migratory birds' physiology: A review

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### Abstract

Migration has come from the latin word "migrare" may be defined as the seasonal movement of animals from one place to another. Bird migration was described by L. Thomson as "changes of habitat periodically recurring and alternating in direction, which tend to secure optimum environment conditions at all times". Temperature, food supply, or the amount of daylight animals migrate, breeding is one of the purposes. Migratory birds undergo two migrations per year: a fall migration and a spring migration. Pre-migratory fattening is the behavior shown by the migratory birds in which they eat food in excess (hyperphagia) and gain weight quickly just to deal with the high energy demands for long migratory flight. This fueling is done before the migratory take off as well as at stopover sites of their routes. Fuel reserves reach maximum levels when birds start long non-stop flight. Feathers' aerodynamic and insulatory functions are affected by long flight and its exposure to light therefore, the plumage is replaced periodically through a process known as molt.

The corticosterone plays a major role in metabolic and behavioral functions to manage fuel utilization on a daily and seasonal basis. Migratory birds usually fly in a V formation and they follow a definite order during migration. Generally adults or old birds start first and the young follow them. Variety of senses helps in the navigation during migratory flight.

It's one of the peculiar system followed by the birds to know their route of migration and is followed by them each and every yearly of their flight. The most commonly used navigation tool is the use of sun compass. Using the sun for direction involves the need for making compensation based on the time. Other abilities include detecting the magnetic fields, visual landmarks and olfactory cues. Anatomical, physiological and molecular analyses have revealed that in birds independent clocks are present at a minimum of three levels: retina of the eyes, pineal gland and hypothalamus. Each of these has input, pacemaker and output components. It is becoming clearer that environmental input to the clock, such as seasonal changes in temperature, rainfall and food abundance, can regulate temporal relationships between physiology and behavior, linked with migration and reproduction.

**Keywords:** migration, migratory birds, navigation, biological clock

### Introduction

Migration has come from the latin word "migrare" may be defined as the seasonal movement of animals from one place to another. Bird migration was described by L. Thomson as "changes of habitat periodically recurring and alternating in direction, which tend to secure optimum environment conditions at all times". In response to changes in temperature, food supply, or the amount of daylight animals migrate, breeding is one of the purposes. Not only mammals, insects, fish and birds they all migrate and at what the distance depend on the species.

Artic tern is found to be covering the longest distance, this travels from Artic to Antarctic, covering a distance of about 22500 km. The birds predominantly migrate from north hemisphere to south hemisphere. Bird migration is a two-way journey onward and return journey from the 'home' to the 'new' places and from the 'new' places to the 'home' and that too very regularly in the same route. Not all species of birds migrate; there are birds which remain all through the year at one place and are called residents.

Migration is actually a series of physiological and behavioral components (Zink, 2002) [28]. Migratory birds undergo two migrations per year: a fall migration and a spring migration. Birds travel the same total distance during both migrations, spring migration is usually faster with fewer stops in between and is to breeding grounds. Spring migration is more energetically expensive than fall migration to feeding grounds. The majority of studies have found that corticosterone levels are higher in migrants during spring versus fall stopovers.

### Types of migration

All species are subject to periodical movements of varying extent.

The birds which live in northern part of the hemisphere have greatest migratory power. On the basis of distance, season, direction etc. migration may be of following types

- A. Daily/Local
- B. Seasonal
- C. Cyclic
- D. Latitudinal
- E. Altitudinal
- F. Longitudinal

#### A. Daily/Local

Birds make daily movements from their nest in response to environmental forces such as light, darkness, temperature, humidity and feeding areas. The house sparrow does not undertake long migration, but it moves out every day from its permanent colony for feeding. Disappearance of paradise flycatcher, golden oriole and pitta at regular intervals is also due to local migration.

#### B. Seasonal

Birds migrate at different seasons of the year for food or breeding, called seasonal migration. Birds that migrate during summer are called summer visitors and that during winters are called as winter visitors.

#### C. Cyclic

Some migrations of birds are seasonal but do not occur at regular intervals. The cyclic migration of the snowy owl in United States in winter occurs in three to five years.

#### D. Latitudinal migration

It usually means the movement from north to south and vice versa. Most birds live in the land masses of the northern temperate and subarctic zones where they get facilities for nesting and feeding during summer. They move towards south during winter and opposite but lesser movement also occurs in the southern hemisphere when the seasons are changed.

#### E. Altitudinal or vertical migration

The altitudinal migration occurs in mountainous regions. Many birds inhabiting the mountain peaks migrate to low lands during winter. Birds migrate either in flocks or in pairs. Swallows and storks migrate a distance of 9650 km from northern Europe to South Africa.

#### F. Longitudinal migration

Movement of birds from east to west and vice-versa. Starlings a resident of east Europe and west Asia migrate towards the

Atlantic coast.

### Why do birds migrate?

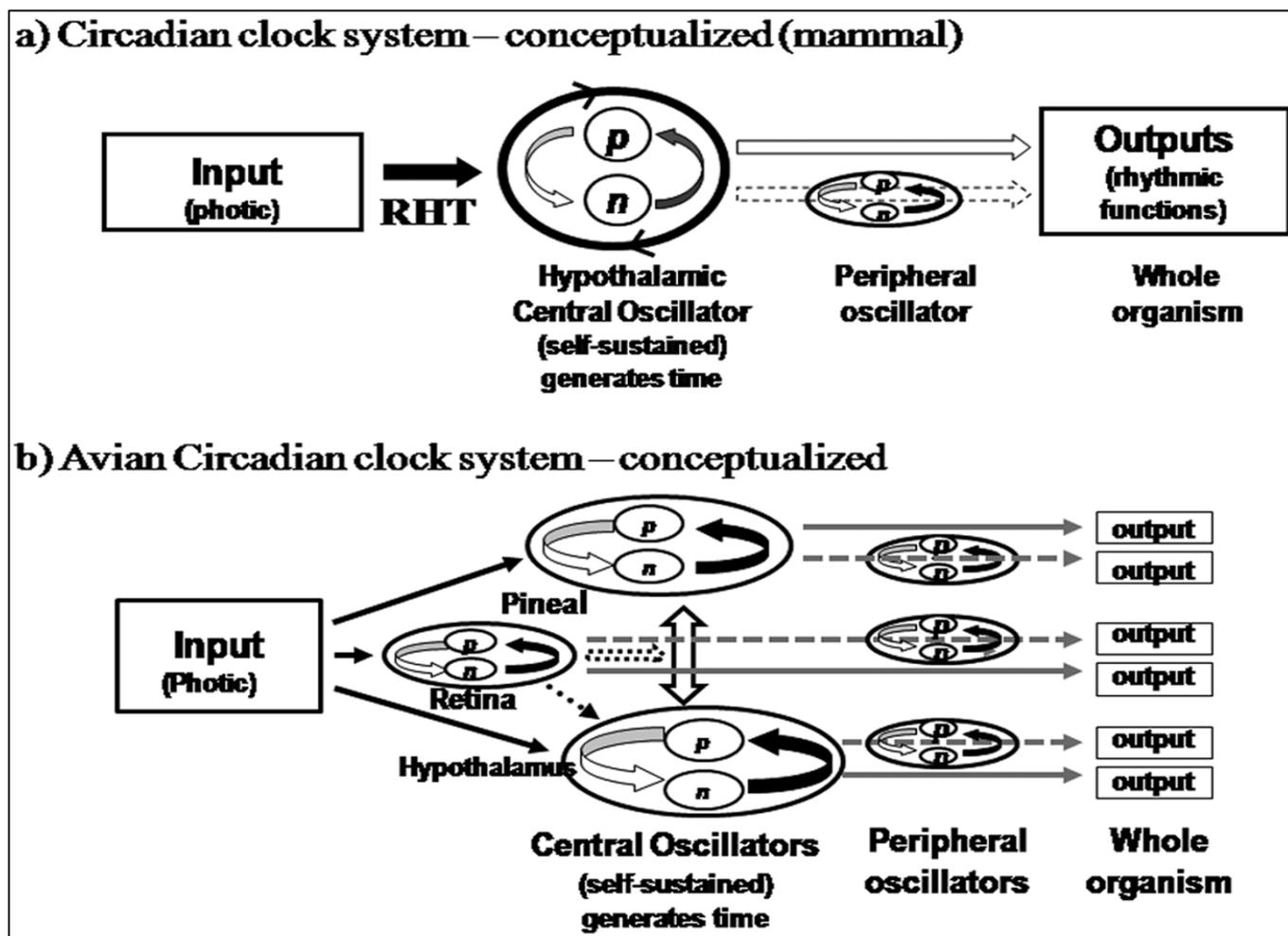
Migratory behavior has evolved as a consequence of seasonal changes in food supplies. Breeding is one of the main reasons along with the food supply. Some migrate to avoid predators and climate extremes.

### Physiology of migration

In annual cycles of migratory birds there are very pronounced physiological and behavioral events such as increased food intake resulting in large depositions of body fat, molt of feathers, migration and reproduction. Each of the events occurs in an orderly and predictable sequence and requires a considerable amount of energy. The phenomenon of migration is controlled by the internal biological clock and by manipulating the photoperiod many researchers have shown that premigratory fattening, molt, gonadal development and migratory orientation can be expressed at different times of the year. The visceral forebrain system (VFS) has been proposed to constitute the neural system that regulates the annual cycle of birds (Kuenzel and Blasher, 1993) <sup>[14]</sup>.

### Biological clock

Birds were one of the first vertebrates in which clock-mediated daily and seasonal events were described. Birds have a system of multiple circadian clocks (Gwinner and Brandsta'tter, 2001 <sup>[9]</sup> and Kumar *et al.*, 2004) <sup>[15]</sup>. Anatomical, physiological and molecular analyses have revealed that in birds independent clocks are present at a minimum of three levels: (1) the retina of the eyes (Yoshimura *et al.*, 2000) <sup>[27]</sup>, (2) the pineal gland (Yoshimura *et al.*, 2000 and Karaganis *et al.*, 2008) <sup>[13]</sup> and (3) the hypothalamus (Yoshimura *et al.*, 2000; Yasuo *et al.*, 2003 <sup>[26]</sup> and Kumar *et al.*, 2004) <sup>[27, 15]</sup>. Each of these has input, pacemaker and output components. Avian pineal has the photoreceptors to detect the light, to generate circadian oscillations and to produce rhythmic melatonin. Light as input is received by the retina, the oscillations are generated within the suprachiasmatic nuclei (SCN) of the anterior hypothalamus and outputs are produced downstream. Unlike mammals, avian clocks are functionally interdependent. Each bird clock interacts with at least one or more other clocks and together forms a centralized clock system (Fig. based on Kumar *et al.*, 2004) <sup>[15]</sup>. According to Chong *et al.*, 2003; Bailey *et al.*, 2002 and Haque *et al.*, 2002 <sup>[4, 1, 10]</sup> some of the clock genes (mostly orthologues of mammalian clock genes) have been identified in the retina and pineal and putative hypothalamic SCN of birds. These include *period* genes (*per2* and *per3*; *per1* has not yet been discovered in birds), cryptochrome genes (*cry1* and *cry2*) and clock and *Bmal* genes *bmal1* and *bmal2*.



**Fig 1:** Circadian clock system as conceptualized in mammals (a) and birds (b; based on Kumar *et al.*, 2004) <sup>[15]</sup>.

### Zugunruhe

Birds undergo daily behavioral shift from inactivity to intense activity at night. Migratory birds exhibit intense bouts of rapid, stereotypic intense nocturnal activity and wing whirring in when kept in captivity this stereotypic behaviour coincides with the onset of the migratory period (Czeschlik, 1977) <sup>[6]</sup>, this is a condition commonly called migratory restlessness or *Zugunruhe*. Vernal migration is the migration of birds from wintering to breeding grounds and this can be initiated by increasing the day lengths of spring and summer. Bartell and Gwinner, 2005 <sup>[2]</sup> reported that vernal and autumnal *Zugunruhe* in some species can be induced in the laboratory by lengthening or shortening the photoperiod, respectively, at the appropriate times of the year. It is assumed that the development of *Zugunruhe* is under the control of a circadian clock as it is photoperiodically regulated event mediated by circadian rhythms. After the end of the vernal migration, fat depletes, body mass declines, and gonads mature and enlarge in size. Gonads will regress as bird enter into photorefractory (birds remain unresponsive to stimulatory effects of long photoperiod) state after the end of reproduction (Malik *et al.*, 2014; Trivedi *et al.*, 2014) <sup>[17, 22]</sup>.

Coverdill *et al.* (2008) <sup>[5]</sup> suggest that the proper expression of migratory restlessness is also influenced by the intensity of ambient light. McMillan, 1972 <sup>[18]</sup> suggested that the removal of the pineal gland, the dominant avian circadian pacemaker, results in a disruption of the daily alteration between *Zugunruhe* and diurnal hopping and feeding behaviors in white-throated sparrows. On the other hand Gwinner *et al.*,

1993 <sup>[8]</sup> found the lowered plasma melatonin levels at night in garden warblers and blackcaps which were quite different and cementing the role of the pineal gland, which synthesizes and systemically releases melatonin at night, for the expression of *Zugunruhe*.

### Pre-migratory fattening

Pre-migratory fattening is the behavior shown by the migratory birds in which they eat food in excess (hyperphagia) and gain weight quickly just to deal with the high energy demands for long migratory flight. This fueling is done before the migratory take off as well as at stopover sites of their routes. Fuel reserves reach maximum levels when birds start long non-stop flight.

### Molt migration

Feathers' aerodynamic and insulatory functions are affected by long flight and its exposure to light (Hedenstroöm, 2003 and Williams and Swaddle, 2003) <sup>[11, 24]</sup>. Therefore, the plumage is periodically replaced by a process known as molt or molting. Birds find a place where they can rapidly replace their flight feathers when moving from the breeding grounds to the winter grounds for resuming the migration. The molting area is usually a place of low predator risk sometimes they have to avoid molt. The reason may be increased predation risk as described by Sillett and Holmes, 2002 <sup>[23]</sup>. There are two molt patterns found to be noticed they are: post - breeding molt when they are in breeding area or a post - migration molt in the wintering area.

### Corticosterone in migration process

In birds corticosterone plays a major role in metabolic and behavioral functions to manage fuel utilization on a daily and seasonal basis (Landys *et al.*, 2006; Ramenofsky and Wingfield, 2007) [16, 21]. Migrating birds' activity patterns alternate between periods of feeding and repose (state of anabolism) and flight (catabolism). It is hypothesized that baseline levels of corticosterone would be elevated during the catabolic or flight stage to coordinate fuel usage and possible behavioral adaptations associated with migratory flight.

### Physiological basis during flight

Flight include take-off, climb, a combination of gliding, bounding, soaring or continuous forward flapping flight, maneuvering, including tight turns involve periods of burst flight. Gliding and soaring flight require least expensive in terms of energy, whereas take-off requires much of the energy. Butler, 2016 [3] described that the continuous forward flapping flight has an intermediate rate of energy expenditure. The early stages of flight can involve both aerobic and anaerobic pathways. Oxygen and metabolic substrates are transported by the cardiovascular system. Oxygen from the lungs and in case of metabolic substrates it is by the gastrointestinal tract and stores of the body that are involved. Cardiac output and respiratory minute volume describes best the functioning of the cardiovascular systems and respiratory system in response to an increase in the demand for oxygen. The increase in Hb concentration has been observed to raise the maximum oxygen carrying capacity of the blood.

There is also a tendency for the masses of the heart and flight muscles to increase during the pre-migratory period in some long distance migrants and these changes relate directly to the overall increase in body mass, which is mainly the result of the accumulation of fat stores (Piersma, 1998 and Piersma *et al.*, 1999) [19, 20].

At the same time, other organs such as the gastrointestinal tract and liver tend to decrease in mass. These changes in sizes of the organs and functions depend mostly on the migratory distance covered by the bird that is having a non – stop flight or the stopovers in their route. All these changes show are examples of phenotypic flexibility and is reversible.

### Thermoregulation during flight

Migration of birds from cooler to warmer areas and vice versa is itself a thermoregulatory behavior. During flight, there is a tremendous increase in heat production, which increases the core temperature.

Thermal conductance increases during flight as well as accelerated counter current mechanism in the brain blood vessels. The respiratory minute volume increases during flying to meet the increased oxygen demand and to enhance heat loss. Birds exposed to moving air or bird moving in air loses much of heat. This phenomenon is termed as forced convection and it is approximately proportional to the square root of the air velocity.

Non-evaporative heat loss is a special process of convection and conduction occurring in the upper respiratory tract, it is similar to counter current exchange pattern and it helps in effective cooling of nasal passage.

Thermal polypnoea is another feature that increases evaporative heat loss by increasing respiratory minute volume and it is characteristic of many hyperthermic panting animals and birds. The extensive air sac system helps the birds to get more ventilation during panting, to accelerate the evaporative

heat loss. Another feature observed in many birds when exposed to heat is the movement of bucco-pharyngeal area to accelerate ventilation that results in evaporative cooling (gular flutter). Tissue fat has the lower conductivity but it does not play a major role in heat conduction.

In birds, fat is deposited in the abdominal cavity because most birds do not have substantial fat layers under the skin. Plumage of birds serves as effective barrier to heat loss from skin surface to environment. Feathers help in trapping the air and act as windproof covering coating of the feathers with oily secretion of preen glands makes the plumage resistant to wet. Some of the birds adapted to freezing temperature have a "cold vasodilatation", by accelerating the blood flow to the foot and extremities that are exposed to cold. It prevent freezing of extremities by increasing the heat loss from these parts. Winter fattening occurs in small birds exposed to cold climate. Thermal conductance of small birds is greater than large birds because of change in the thickness of the skin and fat.

### Order of migration

Migratory birds usually fly in a V formation and they follow a definite order during migration. Generally adults or old birds start first and the young follow them. This seems to be dependent on the maturity of gonads. In the migratory order the adult males will be at the forefront next comes the females then young ones and the wounded birds at the end of the flock. But in the return journey young birds start and the adults follow them. The V formation helps the birds to fly effortlessly for a longer distance as they keep on changing the places at the fore front of the formation. By changing the places helps to take rest for a while and the eddies generated by the birds at the front line helps the birds at the back to fly with minimum or no effort.

### Navigation

Variety of senses helps in the navigation during migratory flight. It's one of the peculiar system followed by the birds to know their route of migration and is followed by them each and every yearly of their flight. The most commonly used navigation tool is the use of sun compass. Using the sun for direction involves the need for making compensation based on the time. Other abilities include detecting the magnetic fields (magneto reception), visual landmarks and olfactory cues.

Innate and experience are the two electromagnetic tools used by the birds. That is why young a bird on its first migration flies in the correct direction. Sun compass is useful during day light and for the night other compasses like moon and stars are used compass. Wiltschko *et al.*, 2006 [25] describes that birds migrate between northern and southern regions, the magnetic field strengths at different latitude, it interpret the radical pair mechanism more accurately and let it know when it has reached its destination. Deutschlander *et al.*, 1999 and Heyers *et al.*, 2007 [7, 12] reported that there is a neural connection between the eye and "Cluster N", the part of the forebrain that is active during migration orientation, suggesting that birds may actually be able to see the magnetic field of the earth.

Stellar cues provided by the stars are obviously important only to nocturnal migrants. Geomagnetic cue is the most controversial and least understood of the major possible navigational cues. In early studies placed birds in a large cement cage with no environmental clues at all; the birds

oriented properly. But when they were put in a large steel cage, which would obviously affect magnetic lines of force around the cage, the birds oriented randomly. Thus, orientation and navigation may be due to a variety of cues. There is some evidence that odors may play a role in navigation, or even sounds (ocean waves, waterfalls).

### Conclusion

Bird migration may be described as “changes of habitat periodically recurring and alternating in direction, which tend to secure optimum environment conditions at all times”. It is usually a response to changes in temperature, food supply or the amount of daylight and is often undertaken for the purpose of breeding. Migratory birds undergo two migrations per year: a fall migration and a spring migration. Pre-migratory fattening is the behavior shown by the migratory birds in which they eat food in excess (hyperphagia) and gain weight quickly just to deal with the high energy demands for long migratory flight. This fueling is done before the migratory take off as well as at stopover sites of their routes. Fuel reserves reach maximum levels when birds start long non-stop flight. Feathers’ aerodynamic and insulatory functions are affected by long flight and its exposure to light therefore, the plumage is replaced periodically through a process known as molt. The corticosterone plays a major role in metabolic and behavioral functions to manage fuel utilization on a daily and seasonal basis. Migratory birds usually fly in a V formation and they follow a definite order during migration. Generally adults or old birds start first and the young follow them. Variety of senses helps in the navigation during migratory flight. It’s one of the peculiar system followed by the birds to know their route of migration and is followed by them each and every yearly of their flight. The most commonly used navigation tool is the use of sun compass. Using the sun for direction involves the need for making compensation based on the time. Other abilities include detecting the magnetic fields, visual landmarks and olfactory cues. Anatomical, physiological and molecular analyses have revealed that in birds independent clocks are present at a minimum of three levels: retina of the eyes, pineal gland and hypothalamus. Each of these has input, pacemaker and output components. It is becoming clearer that environmental input to the clock, such as seasonal changes in temperature, rainfall and food abundance, can regulate temporal relationships between physiology and behavior, linked with migration and reproduction.

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