Introduction to Chronobiology

Chronobiology is a multidisciplinary branch of science dealing with study of biological rhythms. The free-running biological rhythms reflect the endogenous mechanisms of cyclic temporization whose expression is morphologically seen as an internal clock called body clock. All levels of biological integration ranging from ecosystem to subcellular structures exhibit rhythms with diverse frequencies. Periods of most of the documented biological rhythms match with that of any one of geophysical cycles present in the nature. Though circadian rhythms are the most prominent one, ultradian, infradian and circannual rhythms also play vital role in chronobiological homeostasis.
Circadian rhythms are generated by an internal clock, or pacemaker. Therefore, even in the absence of cues indicating the time or length of day, circadian rhythms persist. Circadian rhythms exist even in single cells. In fact, studies have shown that a wide range of cell functions exhibit circadian rhythms. Specific genes called clock genes code for circadian rhythms. Genetic control of circadian rhythms has been examined most extensively in the fruit fly. In mammals, considerable experimental evidence indicates that a region of the brain called the suprachiasmatic nucleus (SCN) is the circadian pacemaker. The SCN, composed of a cluster of thousands of small nerve cells, is located within a region of the brain, called hypothalamus.
Annual biological cycles are widespread in regions both at extreme latitudes as well as close to equator. Activities such as reproduction, growth, molt, migration, and hibernation are timed in an adaptive manner. The most widely used environmental cue for predicting favorable timing of breeding is photoperiod or day length. Photoperiod is the length of the light phase in each daily (24 h) light–dark cycle. Photoperiodism is the biological process of responding to changes in photoperiod.

Biological Rhythm

Biological rhythms are everywhere. The daily changes in sleep and wakefulness, annual bird migration, and the tidal variations in behavior of coastal animals: these are all examples of biological rhythms. The field of chronobiology studies these rhythms in living organisms and how they are tuned by cues from the outside world.

Circadian rhythms (rhythms that repeat approximately every 24 hours) are the most prominent biological rhythms. Not only sleep and wakefulness are influenced by circadian rhythms, also many other bodily functions show a circadian rhythm, such as body temperature, the secretion of hormones, and metabolism, and organ function. These rhythms allow organisms to anticipate and adapt to cyclic changes in the environment that are caused by the daily rotation of the Earth on its axis.

In humans and other mammals, circadian rhythms in the body are synchronized to the environment by a master clock that is located in the suprachiasmatic nuclei (SCN), a tiny brain region that is located just above the crossing of the optic nerves. The SCN receive information about light and darkness directly from the eyes, integrates this input, and relays it to cellular circadian clocks located throughout the rest of the body. In this way, circadian rhythms in behavior and physiology are synchronized to the external light-dark cycle.

Although circadian rhythms require input (such as light) from the environment to synchronize to the 24-h day, a key feature of these rhythms are that they are self-sustained, meaning that they continue to cycle with a period of approximately 24 hours in the absence of any time-giving cues from the environment. Thus, even in constant darkness under controlled laboratory conditions, many bodily functions continue to show an approximately 24-h rhythm. In humans, the intrinsic circadian period is on average 24.2 h, ranging from about 23.5 to 24.6 in the healthy population. This variation in circadian period explains why some people are early birds and others are night owls.

On a molecular level, circadian rhythms are generated by a feedback mechanism involving cyclic changes in the expression of certain genes. The proteins encoded by two of these genes, called CLOCK and BMAL1 switch on the activity of other genes, called Per and Cry. In turn, PER and CRY proteins turn down the activity of CLOCK and BMAL1 proteins, creating a recurring loop of genes being switched on and switched off that repeats approximately every 24 hours. This molecular feedback mechanism is present in virtually every cell in the body – from the cells in your liver to the cells in your skin. Ultimately, it drives the circadian rhythms in cellular processes, metabolism, physiology, and behavior, ensuring all these functions are occurring at the right place at the right time of day.

Disruption to the circadian clock may contribute to health problems. This occurs for example during night shift work or jet lag, in which there is a mismatch between light exposure, food intake, and other cues from the external environment with the timing of the circadian rhythms in the body. In the long term, repeated loss of coordination between the circadian rhythms and environmental cues may increase the risk for a range of diseases such as diabetes, heart disease, and certain types of cancer. Getting in tune with your internal clock may be key to health and wellbeing.

The regulation of circadian rhythms in other organisms, ranging from cyanobacteria to fungi and from plants to insects, all follow the same general principles. Indeed, it was the discovery of the molecular feedback mechanism in fruit flies that led to the Nobel Prize in Physiology or Medicine in 2017. Plants can use their circadian clocks to time flowers to the correct season.

Biological Clocks

Organisms possess a physiological mechanism for measuring time. This is known as **biological clock.**

Each biological rhythm is comprised of repeating units called **cycles.** The length of time required to complete an entire cycle is the **rhythm's period.** The magnitude of the change in activity rate during a cycle is called the **amplitude** and any portion of the cycle is called a **phase.**

Biological clocks or biological rhythms may be characterised by following properties :

1. Whereas temperature changes alter the rate of most chemical reactions and cellular processes, biological rhythms are temperature compensated.
2. Biological clocks are generally unaffected by metabolic pathways or inhibitors that block biochemical pathways within cells.
3. The periods of biological rhythms occur with approximately the same frequency of one or more environmental features.
4. Biological rhythms are self-sustaining, maintaining their normal cycle even in the absence of environmental cues.
5. The biological rhythms can be entrained to environmental cues. The self-sustaining mechanisms may be set and adjusted according to input from the external environment.

Manifestations of Biological Clocks

The basic manifestations of biological clocks are circadian rhythms, circannual rhythms and tidal rhythms.

Circadian Rhythm: Meaning, Examples and Mechanism |

Meaning of Circadian Rhythm:

Circadian rhythm among all other rhythms have been widely studied. The term originated from two Latin words, circa meaning about and dian meaning a day. Circadian rhythm can be defined as an approximately 24 hour physiological pattern that exhibits daily changes in activities. Circadian rhythms are easy to study as they recur within 24 hours in the activity of an individual.

The behavioural response of organisms to environmental rhythms of light and darkness is called photoperiodism, which includes period of illumination (photo phase) followed by a period of darkness (scatophase). Such daily cycles are termed as photoperiod. Animals are not active continuously throughout the 24 hour period.

Majority of them are most active during the daylight hours (diurnal animals). While others are active at night (nocturnal animals). A few animals such as rabbits, sandflies etc. are crepuscular animals who are active during the twilight hours of the day, in early morning (dawn) or early evening (dusk).

Examples of Circadian Rhythm:

A. In Invertebrates:

Circadian rhythm in invertebrates occurs in a number of behavioural patterns ranging from vertical migrations by marine plankton, periodicity or pupal eclosion in dipterians to the dance 'language' of foraging bees.

A few common examples are:

1. In a lake or ocean, phytoplankton photosynthesizes during the daylight hours, occupying the upper region. Zooplankton remain well below the surface at midday when the sunlight is most intense. As darkness approaches, these organisms move upward to feed on the phytoplankton. They sink back to deeper waters after sunrise.

2. Cockroaches are nocturnal and most of their locomotory and feeding activities occur during the hours of darkness. When these animals were placed under experimental situations in which the obvious diurnal factors of light and temperature were removed, it was observed that the rhythmic activity persisted but with a period, which departed significantly from that of the solar day. This natural endogenous circadian clock which is characteristic of an individual cockroach is not calibrated to exact 24 hours condition, but may vary between 23 and 25 hours.

3. Honeybees have great foraging powers. Some flowers blossom once in a day at a specific time. Honeybees reach these flowers at the same time with the help of 'alarm' of its own biological clock.

4. Some intertidal crabs exhibit cyclic variation in their shell colour. They are lighter during the daytime and gets darker as night falls. This prevents their detection from predators.

5. Parasitic animals also show circadian periodicity. The microfilarae of African eye worm (Loa loa) appear in the peripheral circulation of the host (man) in daytime only, going deeper during night. Wuchereria bancrofti (filaria worm) show nocturnal periodicity.

The microfilarae of this endoparasite live by daytime chiefly in large deep-seated blood vessels. But at night they come to lie in the small superficial vessels in the skin. Enterobius vermicularis (pinworm) live in the colon (small intestine) of man at daytime. The gravid females of this worm migrate to perianal region at late night, to deposit eggs in the skinfolds around the anus.

B. In vertebrates:

A few examples of vertebrates exhibiting circadian rhythm are given:

1. To study the circadian periodicity in mouse, a cage outfitted with a device that recorded all the movements of the mouse was taken. When all the records were summarised graphically with appropriate units for the time axis, it revealed a cycle of activity which often reached the peak just after sunset. Very little activity was observed in the middle of the day. Further studies have revealed that hormones were secreted by the hypophysis according to diurnal rhythm.

2. In another experiment Patra (1984), while studying the circadian rhythm of oxygen consumption in three air-breathing fishes (Ambus, Clarias and Channa), observed a clear rhythm in their metabolism. These fishes were most active during the morning hours, when they moved about in search of food. From afternoon onwards they became inactive or remained submerged in water. This rhythmicity is closely related with the diurnal fluctuation of dissolved oxygen.

3. Circadian rhythms may change with the change of place and may also change with age. For example, young woodchucks remain active during the evening only, while their adults remain active almost throughout the day. Similarly, young badgers remain active during the early hours to the middle of the day. As they grow older, their activity time is shifted from evening to night.

4. Two species occupying the same habitat differ in their daily activity rhythms to reduce competition. For example, fly catching birds and bats never come in direct competition for the same food as the birds are diurnal and bats nocturnal.

5. A few birds and smaller mammals, in spite of being homeothermal, show diurnal variations in their body temperature. This is correlated with their changed metabolic activity during day and night. For example, black capped chickadees can decrease their body temperature to as much as 7°C during the night, thus reducing their energy demand by 60%, as the temperature falls in winter.

6. Rhythmicity is also observed in the physiological and biochemical reactions within the body of living organisms. Vijay Lakshmi (1984), while experimenting on albino rats, studied synchronized shifting of liver glycogen and ATPase activity under varied light regime. She maintained rats under 12 hours' light followed by 12 hours' darkness, and then in reverse order.

She also maintained a set of rats under constant light and another set under constant darkness. In the last two situations, rhythmic trend in glycogen, glucose and energy linked enzyme ATPase showed entrainment. Thus, her studies indicated the interdependence of the metabolic and related enzyme activity under varied photoperiodism.

Human circadian rhythm:

Human body also goes through regular biological cycles every day, many of these reach a peak at some regular point during the day or night. G. G. Luce (1973) has suggested that human blood-sugar level, pulse-rate and blood- pressure reach peaks at 5 to 6 p.m. Humans show a periodicity of 24 hours in case of various physiological activities such as hormone levels in blood, blood pressure, EEG, ECG and other activities such as rest cycle, body temperature etc.

The secretion of various hormones from different endocrine glands shows a rhythmic pattern. The most important gland exhibiting this rhythmic pattern is pineal gland. Serotonin hormone, the secretion of this gland, is highest in noon and lowest at midnight, whereas melatonin hormone is highest at night and it stops in the early hours of morning (increased secretion of melatonin hormone makes a person lazy).

Performance of different mental activities such as calculation task, vigilance task, sensory and motor performance, correct signal detection etc., has been found to be affected by the time of day. They are high in the afternoon and early evening and low at night and early morning.

On the other hand, performance on digit span was best in the morning. Thinking also seems to have rhythmic pattern, which slows down at night and increases in the morning. Sensory abilities such as hearing, vision taste and smell are best in late afternoon.

On the basis of certain rhythms, such as compulsory or elective activity, financial or prestigious incentives, social condition and personality etc., two types of persons have been identified – morning types and evening types.

Morning types are at their best in the morning while evening types in the evening. This has a practical implication in industries, such as, morning types should be given morning shifts and evening types evening shifts, which would likely increase their performance.

The above types are also related to personality. Introverts are found to be morning types, while extroverts are evening types. Introverts have higher temperature in the morning and are more aroused during this time. Extroverts, on the other hand, are more aroused during the evening as they have higher temperature than introverts during this time.

On the basis of some practical work conducted on man, Bernard Gittelson was able to distinguish three types of biorhythms:

(i) Physical rhythms, which makes individual feel very active or very sluggish;

(ii) Emotional rhythms, which controls the emotional cycle of an individual; and

(iii) Intellectual rhythms, which is responsible for intellectual alertness and dullness.

Gittelson further put forward that on the basis of the date of birth of an individual, three different charts can be plotted of these three rhythms. If individuals worked according to this chart, he would be benefited to a greater extent.

When all these cycles are at their peak then maximum performance would be expected from an individual. Thus, circadian rhythm affects our day to day performance and, through proper knowledge of these patterns, an individual can achieve his best.

Diagnostic Features of Circadian Rhythms:

1. Circadian rhythm must also persist in laboratory under conditions of continuous light or total darkness and under constant temperature.

2. Circadian rhythm must be able to express itself in light-dark conditions as free running rhythm, showing periods close to – but not equal to – 24 hours.

3. Its free running period must be able to compensate for changes in the surrounding temperature.

4. A circadian rhythm is known to be entrained (it is a process by which an endogenous rhythm is linked with an external geophysical rhythm) by the light-dark and temperature cycles.

5. A circadian rhythm must be able to shift and reset its phase in response to a change in light and dark conditions, and to temperature or chemical disturbance.

Mechanism of Circadian Rhythm:

Three components are believed to be operative for circadian rhythm.

These are:

(a) An Oscillator:

As circadian rhythm is also observed in acellular organisms, it is probably that the oscillator of biological clock resides in the cell. Three theories have been put forward for the precise identification of the clock in the cell:

(i) The plasma membrane:

As the permeability of plasma membrane changes periodically at different times in 24 hours, Giese (1989) is of the opinion that the physiology is changed in circadian way.

(ii) The nucleus:

As rhythm is absent in prokaryotes, it is supposed that the clock might be in the nucleus and acts by changing levels of macromolecular synthesis.

(iii) Geophysical variables:

Some geophysical variables are believed to be responsible for the changed function of a cell membrane or nucleus or both.

(b) A Receptor:

Certain receptors are responsible for the input to the oscillator. These may be in the form of photo-receptors present either in the eyes or pineal gland or in the brain itself.

(c) A Coupling Device:

It is believed that the device that couples the receptor to the oscillator is chemical in nature. Experiments conducted by Truman and Riddiford (1990) with two species of silkworm has revealed that the eclosion (emergence) of moths is controlled by a hormone (chemical) in the brain which can be used to induce eclosion in another species of silkworm. Thus, the coupling device is not species specific.

The following points highlight the five main types of endogenous rhythms seen in animals. The types are: 1. Circadian Rhythm 2. Circa-Tidal Rhythm 3. Circannual Rhythm 4. Circa-Lunar Rhythm 5. Semilunar Rhythms.

Endogenous Rhythm: Type # 1. Circadian Rhythm:

This rhythm is matched with the 24 hour cycle of day and night. We ourselves provide a good example, as we tend to wake up almost at the same time every day in the morning and start feeling sleepy at night. Such circadian rhythms are exhibited by diurnal as well as nocturnal animals.

Endogenous Rhythm: Type # 2. Circa-Tidal Rhythm:

This rhythm is the 12-4 or 24-8 hour tide cycle synchronized with the low and high tides. Organisms living in the intertidal zone (shore crabs, fiddler crabs etc.) are alternately submerged in water and exposed to air. Due to this, pressure, salinity, food supply, temperature and predation also undergo changes. Therefore, animals inhabiting such areas show behavioural periodicity associated with the tides.

Endogenous Rhythm: Type # 3. Circannual Rhythm:

This has been defined as an approximately 365 day physiological pattern that regulates annual changes in activities. This may also be represented in terms of seasonal rhythms (summer, autumn, winter etc.). Circannual rhythms are widespread amongst animals and plants. Different physiological annual rhythms are breeding cycle, hibernation, diapause, migration etc.

Endogenous Rhythm: Type # 4. Circa-Lunar Rhythm:

Circa-lunar or circa-synodic rhythms are synchronized with the phases of the moon. This is the 29.5 days' lunar cycle. Such circa-lunar rhythm are common among marine invertebrates and insects. For example, the annelid palolo worm (Eunice viridis) of the Pacific Ocean (southern hemisphere), rises to the surface to spawn in great numbers when the moon is full during October/November, but the Atlantic palolo worm of the northern hemisphere similarly spawns in the last quarter of the moon in July. Worms isolated in the laboratory produce their gametes at the correct time, showing that this activity is controlled by biological clock of the palolo worm.

Another example is provided by the Jamaican fruit bats that have a pattern of feeding that involves leaving the day roost in the evening and feeding throughout the dark nights during the period of new moon.

However, during full moon they depart from their day roost at the normal time in the evening, but return, back when the moon is high, even when obscured by clouds, suggesting that they make use of an endogenous lunar clock to time their foraging and feeding behaviour.

Endogenous Rhythm: Type # 5. Semilunar Rhythms:

It is the biological rhythms which are synchronized with the fortnightly cycle of spring tide (high tide) and neap tide (low tide). It is also known as circasyzygic or circa-semilunar clocks. Such rhythm is exhibited by periwinkle (Littornia rudis). They show a marked 15 day periodicity in their locomotory activity. The species live high up on the shore and is only covered by the high water of spring tide.