7. Nature's Timekeepers: Unravelling the Effects of Environment on Biological Clock.

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Abstract:

The synchronization of biological processes with the rhythmic patterns of the environment is a fundamental aspect of life. Organisms possesses internal time keeping mechanisms often referred to as biological clocks which enable them to anticipate and adapt to the recurring environmental changes. The profound influence of environmental factors on these biological clocks has become a focal point of scientific inquiry, as understanding this relationship holds implications for health, well-being, and our comprehension of fundamental biological processes. In this chapter we review our current state of knowledge on how the environment effects the circulation of biological cycle, followed by a brief discussion on molecular mechanism which is quintessential manifestation of these internal clocks, unravelling the complexities of this relationship, we aim to contribute to a holistic understanding of nature's timekeepers, paving the way for advancements in chronobiology, followed by case study highlighting the risks related to the floral ambitions on ice in Antarctica. Ultimately, insights gleaned from this exploration hold the potential to inform strategies that optimize the alignment of internal timekeeping systems with the ever-evolving external landscape.

Keywords:

Biological clock, chronobiology, floral ambitions, molecular mechanism.

7.1 Introduction:

Biological clocks, inherent in the intricate tapestry of living organisms, are fundamental to the orchestration of physiological and behavioural processes. Understanding how the environment influences biological clocks is imperative, as disruptions to these internal timekeeping systems can have profound implications for health, behaviour, and adaptation. In an era marked by unprecedented environmental changes, from artificial lighting to climate shifts, unravelling the effects on nature's timekeepers becomes crucial for comprehending the resilience and vulnerabilities of living organisms.

The biological timekeeper is crucial for maintaining delicate temporal organization of physiological and molecular events that are necessary for survival (Brown *et al*). Frequency, period, and amplitude are the three characteristics of rhythms. The number of peaks in a given (such as 60 heartbeats per minute) is known as the frequency. The heartbeat rhythm has a period of around one second, while the human sleep cycle has a period of approximately twenty-five hours when conditions are constant. The period is the amount of time between successive peaks. What changes in magnitude between the peak and the trough is called the amplitude (G Greenberg, MM Haraway). Ultradian rhythms last longer than a day. Circadian rhythms have a period of around one day, while infradian rhythms have a period greater than one day. Circadian (seasonal) rhythms, on the other hand, cycle over a full year.

Animals, plants, and even prokaryotes a class of cell in which the nuclear material is dispersed throughout the cytoplasm of the cell have biological clocks. Prokaryotes are a particular kind of cell that do not have a membrane. The circadian rhythm of photosynthesis and nitrogen fixation, for instance, is observed in the cyanobacterium *Synechococcus*. (Mitsui, Kumazawa, Takahashi, Ikemoto, Cao&Arai,1986). It is widely acknowledged that the first evidence of organisms adapting their physiology and behaviour to the time of day in a circadian manner came from studying the movements of leaves and flowers in plants. These observations have been recorded for a very long time. For instance, mimosa plant leaves open during the day and close at night noticed that the leaf movement rhythm remained constant. Long into the 20th century, the existence of an endogenous circadian clock would eventually come to be accepted.

How Specific Environmental Factors Influence Biological Rhythmic Cycles:

Biological rhythmic cycles are intricately woven into the fabric of life, synchronizing physiological and behavioural processes with the dynamic external environment. Several environmental factors significantly influence the delicate orchestration of these internal timekeepers. The quality and quantity of light, encompassing its intensity, duration, and spectrum, serve as potent influencers on circadian rhythms. Natural sunlight, with its full spectrum, is a fundamental entrainer for many organisms, impacting the timing of activities and seasonal transitions. Daily and seasonal temperature variations play pivotal roles in entraining biological rhythms. Organisms often exhibit temperature-compensated circadian rhythms, ensuring stability across changing thermal landscapes and influencing metabolic processes.

Social interactions and behavioural cues from conspecifics contribute significantly to the synchronization of biological rhythms, especially in social animals. Group dynamics, communication, and shared activities influence sleep-wake cycles and circadian alignment. Photoperiodic responses triggered by seasonal changes in day length impact reproductive behaviours, molt cycles, and other seasonal adaptations. Temperature variations and shifts in food availability further modulate biological rhythms, influencing migration, hibernation, and breeding patterns.

Artificial light exposure, particularly during the night, can disrupt melatonin production and circadian rhythms. Light pollution in urban areas alters natural dark-light cycles, affecting the behaviour and physiology of both diurnal and nocturnal species. Changes in altitude and atmospheric pressure influence oxygen availability, impacting the timing of physiological functions, particularly in species adapted to different altitudes. Circadian adaptations may occur in response to variations in oxygen levels and temperature. Plants release volatile compounds that influence the behaviour and biological rhythms of neighbouring organisms. Environmental cues such as changes in humidity, barometric pressure, and magnetic fields also play roles in shaping circadian responses.

Understanding these nuanced interactions between biological rhythms and the environment provides valuable insights into the adaptability and resilience of organisms.

7.2 Molecular Mechanism of Biological Clock:

In the realm of scientific world, biological clock is a relatively new concept. Jeffrey C. Hall, Michael Rosbash, and Michael W. Young have been awarded the 2017 Nobel Prize in Physiology or Medicine in recognition of their findings about the molecular mechanisms governing circadian rhythms. Circadian rhythms are driven by an internal biological clock that anticipates day/night cycles to optimize the physiology and behaviour of organisms.

Jeffry and his colleagues discovered that the clock gene in drosophila controlled circadian rhythm which is homologous in wide range of organisms. When it comes to drosophila, the per (period)gene serves as the primary process regulator. Period genes produce period proteins and mRNA, which are shuttled between the nucleus and cytoplasm.

Period mrna expression decreased as a result of period protein accumulation. The peak of per mrna level occurred early in the night and several hours before the peak in per protein abundance. Another regulator that can bind to period protein is tim protein, which is encoded by the timeless gene. The accumulation of period proteins and the suppression of the period gene depend on this interaction.

Activation of tim and per gene.

Period gene and tim gene transcription is positively regulated by clock (clk)and cycle(cyc) protein. Clk and cyc interact with each other and bind to a specific element of per and tim gene and act as an enhancer which increased the expression of this genes.

Delayed transcription and translation

Transcription of per mrna and translation of per protein synthesis is delayed due to some effector proteins.

DBT (Double time protein)- coded by DBT gene that phosphorylates per protein and increases its degradation. Cry (Cryptochrome)- When dawn arrives, light activates the protein product of the cryptochrome gene, promoting its binding to TIM and causing its breakdown. This leaves it open to phosphorylation by DBT, which leads to further destruction. Insights to the world of molecular mechanism in response to environmental changes. Different organisms have different methods of regulating the biological cycle, below are example of its examples.

7.2.1 The Molecular Mechanism of Circadian Clock in Synechococcus Elongatus is Presented Here:

The three genes in *S. elongatus* that control chromosomal compaction, cell division time, and pattern of gene expression are Kai A, Kai B and Kai C.

The primary component is the hexameric protein Kai C. The N and C terminal domains of the compound combine to produce the two rings-CI and CII. A loop refers to the peptide at the C terminus of the CII ring. Two amino acid residues Serine and Threonine are present in the CII ring at positions 431 and 432, respectively. Kai C possesses both autokinase and autophosphatase properties. When daylight arrives, Kai C is in an unphosphorylated condition where both the rings are weakly affixed, and the A loop remains exposed.

By morning, Kai A binds to loop A which causes threonine at position 432 to autophosphorylate and the serine at position 431 to phosphorylate as well. Kai C gets phosphorylated by nightfall. As a result, the CII ring stacks onto the CI ring, exposing the B loops on the lower side of the CI ring. Additionally, A loops become obscured.

Conversely, KaiB transforms from an inactive tetramer to an active monomer by dusk. Active Kai B binds to the B loop. As the night progresses, Kai A is unable to attach to it and Kai B sequesters its alternate structure. Since Kai A is no longer restricted to CII ring, KaiC dephosphorylates threonine and serine by activating its autophosphatase activity.

By dawn, Kai C reverts to its unphosphorylated form, exposing the A loops once more.

The following day, the cycle repeats again. Kai C, the central component of the cyanobacterial circadian clock oscillator, changes its phosphorylation form throughout the day and night. Controls the expression of genes that drive the physiology of cyanobacteria as a consequence. But the Kai oscillator doesnot directly control gene expression. It functions by means of the circadian output components-

- Histidine Kinase- *Synechococcus* adaptive sensor (Sas A)
- Cognate Response regulator- regulator of phycobilisome association A (Rpa A)
- Phosphatase- Circadian input Kinase (Cik A)

Interaction Of Kai C And the Circadian Output Components

When Kai C is in phosphorylation mode during the day, Sas A binds to it and undergo autophosphorylation. Phosphorylated SasA transfers its phosphate to Rpa A, upon binding to Kai C. An increase in Kai C phosphorylation results an increase in Sas A binding to Kai C and autophosphorylation, which phosphorylates additional Rpa A. At twilight, Kai C can be bound by a unique kind pf Kai B. Kai B transition from an idle tetramer to a responsive monomer state. SasA's domain and active KaiB are structurally similar. Kai B competes with SasA for binding to Kai C as a result of being active.

The current theory holds that Kai B can knock SasA from Kai C. As the night wears on, Kai A is sequestered by active Kai B in an inactive form. The more Kai B attaches to Kai Cat B loop, bound Kai B draws Cik A. After attaching itself to the complex, Cik A dephosphorylates Rpa A by acting as phosphatase. Rpa A becomes increasingly dephosphorylated over time. Hence by the end of the night, the phosphorylation level is quite low. A rhythm of Rpa A phosphorylation is produced by the interaction of Sas A and Cik A with the Kai oscillator, and this rhythm peaks at around sunset. Rpa A is a transcription factor.

The promoter of class 1 gene can be bounded by phosphorylated Rpa A and the non-phosphorylated version of Rpa A cannot attach to the promoter, so transcription is not possible in this case. Therefore, the expression of class 1 gene peaks at nightfall and decreases at dawn, and is regulated by the rhythm of phosphorylated Rpa A. Conversely, the promoter of Class 2 gene can bind to non-phosphorylated Rpa A but not phosphorylated Rpa A. Class 2 gene expression is regulated by it; it increases at dawn and decreases at evening. Rpa A phosphorylation, thus, controls the circadian output of oscillating class 1 and class 2 gene expression. Thus, for gene expression, Kai oscillator is connected to the circadian output components Sas A, Cik A and Rpa A, maintaining a synchronization with the Day-Night cycle of Environment.

7.3 An Explanation of Clock Regulation in The Leaves of *Arabidopsis*:

Proteins regulating the mechanism include- LHY (Late Elongated Hypocotyl), CCA1(Circadian Clock Associated 1), TOC1(Timing of CAB Expression 1), PRR7(Pseudo Response Regulator 7), PRR9(Pseudo Response Regulator 9), PRR3(Pseudo Response Regulator 3), ZTL(Zeitlupe), two hypothetical protein X and Y. CCA1 and LHY are primarily considered to be morning genes while TOC1 is thought to be the most significant evening gene. These are the elements that cause the clock to synchronize with the 24-hour cycle on Earth.

At dawn, CCA1 and LHY proteins are synthesized. These proteins functions as negative feedback loop by upregulating the synthesis of PRR7 and PRR9, which in turn downregulates the expression of CCA1 and LHY. Concurrently, CCA1 and LHY also suppress the expression of the evening gene, TOC1. At dusk, when the concentration of both CCA1 and LHY drop, TOC1 gets expressed. The putative component Y, whose activity may be partly provided by GI, product of the gene *Gigantea*, is regulated by TOC1 i.e. TOC1 controls the expression of its own activator. Another fictitious gene called X is thought to be upregulated by TOC1. X increases the expression of the morning genes, CCA1 and LHY. It is thought that TOC1, PRR3, ZTL and GI interact in a post -transcriptional regulatory manner. ZTL reduces TOC1 activity throughout the day since it needs light to function. ZTL binds to TOC1 and target it for degradation by the proteasome. The PRR3 downregulates this inhibition. Furthermore, at twilight, GI is triggered, and TOC1 is upregulated because ZTL can no longer operate in the absence of light.

Even while it is evident that the relative abundances of the clock gene products at various times of the day regulate the expression of other plant genes, little is known about the mechanism underlying this regulation of the plant circadian clock's output.

7.4 Environmental Changes and The Biological Clock's Adjustment to Them:

A change or disruption of the environment is referred to as environmental change, and it is typically brought by natural biological processes and anthropogenic impacts. Natural events like volcanic eruptions, floods etc. have contributed to some of these changes, but human actions like deforestation, fossil fuel burning, raising cattle, and other activities produce copious amounts of greenhouse gases. The primary causes of the global environmental change are the greenhouse effect and global warming that follow.

All life on Earth will be impacted by environmental change if the current situation continues in the same way. The earth’s temperature will increase, monsoon patterns will shift, the sea levels will rise, and there will be frequent storms, volcanic eruptions and natural disasters.

Geomorphic processes in periglacial environments are expected to be significantly impacted by global environmental change. Significant changes in the distribution of periglacial and permafrost landforms, as well as land forming processes, have been brought about by the notable global warming that has taken place during the late twentieth century.

Permafrost will probably continue to melt as the temperature warms, which will have a substantial impact on the frequency and number of geomorphic processes. All life on Earth is probably going to be significantly impacted by changes in the permafrost’s state and the ensuing effects on landforms and land-forming processes.

The Environment system and human activity play a role in environment change by transforming and transporting vast amounts of energy and minerals. Material and energy have been converted by human activity into goods and services that satisfy human needs and desires.

These days, human activity is changing the natural flow system on a scale never seen before. Humans fix nearly as much sulphur and nitrogen in the atmosphere as does nature. By releasing significant amounts of carbon into the atmosphere through the burning of fossil fuels, we are also changing the Carbon cycle.

The Earth has lost six million square kilometres of forest since the eighteenth century, and the rate at which land is being depleted to the point that its biological function is comprised has also increased. The biological clock, which is part of our natural ability to adapt to changes in our environment, is eventually impacted by these changes on a global scale. Crucially, for our survival, the biological clock senses these changes and modifies its internal system accordingly. Some of the case studies serve as an evident to it.

7.5 Antarctica's Blossoming Flowers: The Concerning Ramifications (Case Study):

Antarctica typically experiences year-round intense cold. Antarctica uses a variety of methods to control the temperature on Earth, which is a critical function. The ice-albedo feedback is the most important one. A considerable amount of sunlight is reflected back into space by the massive ice sheets and glaciers, aiding in the planet's cooling. Sea ice forms in Antarctica as a result of the region's frigid temperatures, which amplifies the reflecting effect. As antarctica covered with ice it's not easy for plants may thrive there but some unique ones are able to survive despite the challenging conditions. In Antarctica, there are two flowering plants (Antarctic hair grass and Antarctic pearlwort) that are expanding far more quickly than they did previously and also started to be blooming.

Climate change, more specifically the warming of the climate, is to blame for this. The warming influence causes plants to alter their internal flowering clock and establish a new internal blooming cycle.

On an island in the frigid continent named Signy Island, scientists have been researching these plants. When compared to the years from the 1960s to 2009, some of these plants grew ten times quicker between 2009 and 2019. According to a New Scientist report, the other plants grew five times quicker than they had previously. This is not a good sign for earth and the whole mankind.

7.6 Conclusion:

With the discovery that self-sustaining transcription/ translation feedback loops are the essential part of the molecular mechanism by which clock genes control circadian oscillation in cell and tissue, a new paradigm in our understanding of how organisms anticipate and adapt to regular daily environmental cues like light has emerged.

It keeps in sync with Earth's 24-hour cycle by sensing changes in its environment and responding appropriately. Gene transcription and translation oscillations have been brought about by the biological clock in response to the slow changes in the global environment.

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