University of Groningen

Circadian Pacemaker – Temperature Compensation

Gerkema, Menno P.

Published in:
Encyclopedia of Neuroscience

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2009

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Gerkema, M. P. (2009). Circadian Pacemaker – Temperature Compensation. In M. D. Binder, N. Hirokawa, & U. Windhorst (Eds.), *Encyclopedia of Neuroscience* (pp. 730-731).

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

8. Lee CC (2005) The circadian clock and tumor suppression by mammalian period genes. *Meth Enzymol* 393:852–861
9. Turek FW, Joshu C, Kohsaka A, Lin E, Ivanova G, McDearmon E, Laposky A, Losee-Olson S, Easton A, Jensen DR, Eckel RH, Takahashi JS, Bass J (2005) Obesity and metabolic syndrome in circadian clock mutant mice. *Science* 308:1043–1045

Circadian Desynchronization/ Circadian Desynchrony

- Circadian Sleep Phase Syndromes

Circadian Food Anticipatory Activity (FAA)

- Food Entrainment

Circadian Output Genes

- Clock-Controlled Genes

Circadian Pacemaker – Temperature Compensation

MENNO P. GERKEMA

Department of Chronobiology, Faculty of Mathematics and Natural Sciences, University of Groningen, Groningen, The Netherlands

Definition

One of the defining characteristics of circadian pacemakers and indicates the independence of the speed of circadian clock processes of environmental temperature. Mechanisms involved, so far not elucidated in full detail, entail at least two processes that are similarly

affected by temperature changes, but with an opposing and counterbalancing effect on the periodicity of the clock system. As a result of temperature compensation, the increase in reaction velocity for every 10° rise in temperature (► Q_{10}) of processes governed by ► circadian pacemakers reaches values of about 1.

Characteristics The Phenomenon

The first study on temperature independence in circadian timing was published in 1932 [1], showing the precision in time memory of foraging bees in spite of changes in environmental temperature. The early notion that the velocity of circadian processes does not vary with environmental temperature (within certain ranges) has been based on experimental evidence from a wide variety of sources. Evidence for temperature compensation of circadian rhythms has been collected for luminescence rhythms in unicellular algae, daily leaf movements in plants, and locomotor activity in cockroaches and lizards (as compiled in [2]). Comparisons of ► period length, expressed as Q_{10} , the quotient of reaction rates per 10°C, revealed Q_{10} s in the range of 0.9–1.2 [3]. This is in sharp contrast to the usually temperature-dependent kinetics of biochemical processes resulting in Q_{10} values of roughly 2–3 [4]. These findings, together with the insight that a functional clock subject to temperature dependence would be prone to inaccuracy in the natural environment, caused Pittendrigh to list temperature compensation as item XI on his famous list of 16 empirical generalizations about circadian rhythms [3]. Since then, a vast literature on circadian Q_{10} values has accumulated, confirming early observations. Recently, temperature compensation has been demonstrated in ► clock gene expression rhythms in mammalian fibroblast cultures [5]. Also the phosphorylation rhythms of the Cyanobacterial protein KaiC *in vitro*, in the presence of two other proteins but in absence of transcription and translation, shows temperature compensation, in the range of 25–35°C [6].

Mechanism

A simple model for temperature compensation has been based on two chemical reactions, both of which are temperature-dependent. The rate of the first reaction may control period length, whereas the product of the second reaction would inhibit the first reaction. With such a model, Q_{10} values slightly smaller than 1 also can be explained [7]. Temperature compensation also is an important aspect of neuromodulation (e.g., motor networks), and here again the intrinsic temperature dependences of the processes that contribute to the system output can simply balance each other because reaction rates have been “chosen properly” [8].

Alternatively, the structure of the network itself can stabilize its output, as also has been suggested for networks in clock systems, emphasizing pathway phenomena rather than results of single enzyme properties [9]. The hunt for molecular key players in the process of temperature compensation has nevertheless started, as illustrated in a study on the role of specific core clock proteins in *Arabidopsis* [10].

References

1. Wahl O (1932) Neue Untersuchungen über das Zeitgedächtnis der Bienen. *Z vergl Physiologie* 16:529–589
2. Bünning E (1958) *Die physiologische Uhr*. Springer, Berlin
3. Pittendrigh CS (1960) Circadian rhythms and the circadian organisation of living systems. In: Cold spring harbor symposia on quantitative biology XXV, Long Island, New York, pp 159–184
4. Hoff JH van 't (1884) *Études de dynamique chimique*. Muller, Amsterdam
5. Tsuchiya Y, Akashi M, Nishida, E (2003) Temperature compensation and temperature resetting of circadian rhythms in mammalian cultured fibroblasts. *Genes Cells* 8:713–720
6. Nakajima M, Imai K, Ito H, Nishiwaki T, Murayama Y, Iwasaki H, Oyama T, Kondo T (2005) Reconstitution of circadian oscillation of cyanobacterial KaiC phosphorylation in vitro. *Science* 308:414–415
7. Hastings JW, Sweeney B (1957) On the mechanism of temperature independence in a biological clock. *Proc Natl Acad Sci USA* 43:804–811
8. Zhurov Y, Brezina V (2005) Temperature compensation of neuromuscular modulation in *Aplysia*. *J Neurophysiol* 94:3259–3277
9. Ruoff P, Zakhartsev M, Westerhoff HV (2007) Temperature compensation through systems biology. *FEBS J* 274:940–950
10. Gould PD, Locke JCW, Larue C, Southern MM, Davis SJ, Hanano S, Moyle R, Milich R, Putterill J, Millar AJ, Hall A (2006) The molecular basis of temperature compensation in the *Arabidopsis* circadian clock. *The Plant Cell* 18:1177–1187

Circadian Pacemaker Neuron

Definition

Circadian rhythms of animal behavior and physiology are coordinated by a master clock in the central nervous system of each individual. This master clock comprises a collection of multiple circadian pacemaker neurons.

Each pacemaker neuron has the capacity for autonomous circadian oscillation of cellular parameters such as gene transcription and action potential firing rate. Pacemaker neurons communicate circadian phase information to one another – for the purpose of

synchronizing or otherwise coordinating their autonomous rhythms – and to downstream neural targets – for the purpose of driving overt behavioral and physiological rhythms. This communication of phase information occurs via both classical synaptic neurotransmission and the release of peptide neuromodulators.

- Cellular Clock
- Circadian Rhythm
- Human Circadian Timing System
- Morning/Evening Oscillators

Circadian Rhythm

Definition

A circadian rhythm is a biological oscillation that has a frequency of about once per 24 h when conditions are constant (e.g., when removed from regular, 24 h daily cycles of the environment, such as light and dark or warm and cold). The word “circadian” is derived from *circa* dies, Latin for “about a day.” Circadian rhythms are synchronized to exactly 24 h under natural conditions by zeitgebers, with light acting as the major synchronizing agent.

- Chronobiology
- Entrainment
- Human Circadian Timing System

Circadian Rhythm Sleep Disorders

- Circadian Sleep Phase Syndromes

Circadian Rhythms of Autonomic Functions

RUUD M. BUIJS

Instituto de Investigaciones Biomedicas, Department Fisiologia, Universidad Nacional Autonoma de Mexico, Mexico City, Mexico

Synonyms

Circadian rhythms are all biological rhythms that express themselves with a rhythm of ~24 h.