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Introduction to the Special Issue on Circadian Rhythms in Behavioral Neuroscience

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Circadian rhythms influence virtually every aspect of behavior. This special issue provides updates on the current state and future directions for the field of circadian rhythms in behavioral neuroscience. Recent data have linked circadian rhythms to behavioral and physiological phenomena and disease states in virtually every area of behavioral and biomedical science. Specifically, a growing interest in the cognitive, neuropsychiatric, and metabolic consequences of circadian rhythm disorders and dysfunction is emerging. This special issue is not intended to provide an exhaustive overview of the entire field of chronobiology or behavioral rhythms. Instead, we invited researchers from a variety of fields to critically review and integrate studies that address the roles of circadian rhythms in behavioral neuroscience. The papers included in this issue range from the molecular biology of clock genes to the behavior of free-living animals, and cover a wide variety of species ranging from insects, to rodents, to humans. As such, the reviews provide an overview of the burgeoning field of circadian rhythms within behavioral neuroscience.

Keywords: circadian rhythms, behavioral neuroscience, learning and memory, mood disorders, clock genes

Circadian rhythms influence virtually every aspect of behavior. Nonetheless, beyond locomotor rhythms, relatively little attention is paid to the importance of circadian biology for behavioral neuroscience. Therefore, this special issue focuses on the role of circadian rhythms in learning and memory, affect, sleep, drug abuse, and other related phenomena.

This special issue was conceived to provide an update on the current state and future directions for the field of circadian rhythms in chronobiology. There are significant challenges ahead, but this is also a period of tremendous growth in the appreciation of circadian rhythms in all aspects of biology. Recent years have brought data linking circadian rhythms to behavioral and physiological phenomena and disease states in virtually every area of behavioral and biomedical science (Bass & Takahashi, 2010; Froy, 2011; Gerstner & Yin, 2010; Scheiermann, Kunisaki, & Frenette, 2013). In particular, there has been growing interest in the cognitive, neuropsychiatric, and metabolic consequences of circadian rhythm disorders and dysfunction (Bass, 2012; Kondratova & Kondratov, 2012; Kronfeld-Schor & Einat, 2012). The ongoing challenge for circadian rhythms research includes: (1) finding ways to treat circadian rhythm dysfunction in disease, (2) translating the advances in basic neural and molecular biology of circadian rhythms to the clinic, and (3) solving a fundamental difficulty in linking the role of circadian phenomena, including clock gene expression, to behavioral and physiological processes. Although it is technically feasible to delete or overexpress clock and related genes in the nervous system, we have not yet advanced to a state where we can cleanly adjust the phase relationship or rhythmicity of a clock component independently, a manipulation that will be necessary for a deeper understanding of the biology of rhythms. Addressing these issues will not be simple and there is an ever-growing list of experimental and clinical problems that will require the attention of circadian biologists. However, the potential upside for both basic and clinical biology is enormous as the circadian system impacts virtually every animal cell and tissue. A deeper understanding of the specifics of these interactions is likely to provide insights beyond circadian biology.

This special issue is not intended to provide an exhaustive overview of the entire field of chronobiology or behavioral rhythms. Instead, we invited researchers from a variety of fields to critically review and integrate studies that address the roles of circadian rhythms in behavioral neuroscience. The papers included in this issue range from the molecular biology of clock genes to the behavior of free-living animals. Further, a variety of species are covered in this issue including insects, rodents, and humans. As such, the reviews provide an entŕe into the larger field of circadian rhythms in behavioral neuroscience.

The papers are loosely grouped into categories including adaptive function, sleep, learning and memory, behavioral feedback to the

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circadian clock, clock genes, circadian rhythms and mood, and finally, the chronobiology of substance abuse disorders and reward pathways.

In the lead article, Patricia Decoursey reviews the evidence for an adaptive role for circadian rhythms by discussing the consequences of suprachiasmatic lesions for small mammal behavior and survival in the wild. Her review suggests that some mammals require very low light levels for entrainment. It is important that she provides evidence to support the assertion that circadian rhythms are adaptive by comparing the survival of SCN-lesioned animals with SCN-intact counterparts (DeCoursey, 2014, pp. 240–249).

The next two papers discuss the role of sleep, a key output of the circadian system, in the context of circadian rhythms. Mark Blumberg and colleagues discuss the development of sleep/wake cycles in young rodents with particular emphasis on behavioral and neural circuit development in the context of circadian rhythms (Blumberg, Gall, & Todd, 2014, pp. 250–263). Next, Alexandra Nall and Amita Sehgal review the biology of monoamine signaling pathways in the regulation of sleep states in *Drosophila*, a model system that has provided great insight into the molecular biology of circadian rhythms (Nall & Sehgal, 2014, pp. 264–272).

The next two papers address the role of circadian rhythms and circadian disruption in CNS function. First, Craig Heller and colleagues hypothesize that excitatory–inhibitory balance affects many types of cognitive dysfunction. They suggest that the circadian system and sleep are intimately involved in regulating overall excitation and neural plasticity and that many forms of mental retardation may be related to abnormal inhibition (Heller, Ruby, Rolls, Makam, & Colas, 2014, pp. 273–282). The next paper discusses the role of circadian biology in learning and memory from a different perspective. Specifically, Benjamin Smarr and colleagues describe the way daily rhythms and circadian disruption regulates learning and memory via intracellular signaling pathways, neurogenesis, and epigenetic modifications. Importantly, they describe how the hippocampus both encodes time-of-day information into memories and is modulated by the time of day in which events occur. This has important implications for memory formation (Smarr, Jennings, Driscoll, & Kriegsfeld, 2014, pp. 283–303).

Next, Ian Webb and colleagues invert the usual paradigm for discussing how circadian rhythms control behavior to discuss how behavioral feedback, arousal, and related neurochemicals can modulate or entrain circadian rhythms. This paper raises the possibility that nonphotic inputs to the clock could be engaged to modulate or strengthen circadian clocks in humans (Webb, Antle, & Mistlberger, 2014, pp. 304–325).

In the next section, three papers discuss the role of circadian biology and clock genes in the regulation of mood states. First, Schnell and colleagues review the literature linking circadian dysfunction to mood states and delve into potential neuronal mechanisms including monoamine transmission, hypothalamic pituitary adrenal axis activity, and neurogenesis. Further, they suggest that chronotherapy to treat circadian dysfunction may have important beneficial effects for patients with mood disorders (Schnell, Albrecht, & Sandrelli, 2014, pp. 326–343). In the subsequent paper, Dominic Landgraf and colleagues discuss the links between circadian biology and human psychiatric disorders and review the behavioral consequences of specific clock gene mutations in animals. The interactive links among circadian rhythms, mood disorders, clock genes, light, and sleep have been extensively documented. However, as this paper emphasizes, it has been difficult to directly and causally link these phenomena, but new tools are leading to increasingly rapid progress (Landgraf, McCarthy, & Welsh, 2014, pp. 344–359). Asarnow and colleagues next discuss mood disorders in human patients and how they are linked to sleep and circadian dysfunction. Additionally, this paper reviews current state-of-the-art treatments for sleep and circadian dysfunctions associated with mood disorders. This paper also focuses on the rapid antidepressant effect of sleep deprivation and how this can inform the relationships among sleep, circadian rhythms, and mood (Asarnow, Soehner, & Harvey, 2014, pp. 360–370).

In the final section, Amanda Damaggio and Michael Gorman discuss the chronobiology of ethanol consumption. Specifically, they review circadian disruption as a risk factor for alcohol abuse, the manner in which alcohol exposure can alter circadian rhythms, and finally circadian variation in the development of alcohol addiction and physical dependence. For instance, circadian disruption or clock gene mutations increase spontaneous drinking behavior and restricting access to alcohol to the dark phase significantly increases alcohol intake (Damaggio & Gorman, 2014, pp. 371–386). In the final paper, Ryan Logan and colleagues explore the circadian relationship with addiction in both human and nonhuman animals before delving into the molecular mechanisms linking clock genes to the reward system and the development of addiction. In particular, they describe the role of *clock* in dopaminergic cells in modulating the rewarding effects of drugs. The ClockΔ19 mice, which lack functional *clock*, exhibit enhanced intake of both cocaine and alcohol (Logan, Williams, & McClung, 2014, pp. 387–412).

With this special issue, we have endeavored to provide readers with an overview of the dynamic and bidirectional relationships among brain, behavior, and the circadian system. All together, these reviews highlight the importance of considering the time of day of drug administration, learning and memory tests, as well as other behavioral assessments when designing experiments. More broadly, it is our hope that the articles contained in this issue will inspire research into the dynamic role of circadian rhythms in scientific problems both old and new.

References

Asarnow, L. D., Soehner, A. M., & Harvey, A. G. (2014). Basic sleep and circadian science as building blocks for behavioral interventions: A translational approach for mood disorders. *Behavioral Neuroscience, 128,* 360–370. doi:10.1037/a0035892

Bass, J. (2012). Circadian topology of metabolism. *Nature, 491,* 348–356. doi:10.1038/nature11704

Bass, J., & Takahashi, J. S. (2010). Circadian integration of metabolism and energetics. *Science, 330,* 1349–1354. doi:10.1126/science.1195027

Blumberg, M. S., Gall, A. J., & Todd, W. D. (2014). The development of sleep−wake rhythms and the search for elemental circuits in the infant brain. *Behavioral Neuroscience, 128,* 250–263. doi:10.1037/a0035891

Damaggio, A. S., & Gorman, M. R. (2014). The circadian timing system in ethanol consumption and dependence. *Behavioral Neuroscience, 128,* 371–386. doi:10.1037/a0036408

DeCoursey, P. J. (2014). Survival value of suprachiasmatic nuclei (SCN) in four wild sciurid rodents. *Behavioral Neuroscience, 128,* 240–249. doi:10.1037/a0036696

Froy, O. (2011). Circadian rhythms, aging, and life span in mammals. *Physiology*, *26*, 225–235. doi:10.1152/physiol.00012.2011

Gerstner, J. R., & Yin, J. C. (2010). Circadian rhythms and memory formation. *Nature Reviews Neuroscience*, *11*, 577–588. doi:10.1038/nrn2881

Heller, H. C., Ruby, N. F., Rolls, A., Makam, M., & Colas, D. (2014). Adaptive and pathological inhibition of neuroplasticity associated with circadian rhythms and sleep. *Behavioral Neuroscience*, *128*, 273–282. doi:10.1037/a0036689

Kondratova, A. A., & Kondratov, R. V. (2012). The circadian clock and pathology of the ageing brain. *Nature Reviews Neuroscience*, *13*, 325–335. doi:10.1038/nrn3208

Kronfeld-Schor, N., & Einat, H. (2012). Circadian rhythms and depression: Human psychopathology and animal models. *Neuropharmacology*, *62*, 101–114. doi:10.1016/j.neuropharm.2011.08.020

Landgraf, D., McCarthy, M. J., & Welsh, D. K. (2014). The role of the circadian clock in animal models of mood disorders. *Behavioral Neuroscience*, *128*, 344–359. doi:10.1037/a0036029

Logan, R. W., Williams, W. P. III, & McClung, C. A. (2014). Circadian rhythms and addiction: Mechanistic insights and future directions. *Behavioral Neuroscience*, *128*, 387–412. doi:10.1037/a0036268

Nall, A., & Sehgal, A. (2014). Monoamines and sleep in *Drosophila*. *Behavioral Neuroscience*, *128*, 264–272. doi:10.1037/a0036209

Scheiermann, C., Kunisaki, Y., & Frenette, P. S. (2013). Circadian control of the immune system. *Nature Reviews Immunology*, *13*, 190–198. doi:10.1038/nri3386

Schnell, A., Albrecht, U., & Sandrelli, F. (2014). Rhythm and mood: Relationships between the circadian clock and mood-related behavior. *Behavioral Neuroscience*, *128*, 326–343. doi:10.1037/a0035883

Smarr, B. L., Jennings, K. L., Driscoll, J. R., & Kriegsfeld, L. J. (2014). A time to remember: The role of circadian clocks in learning and memory. *Behavioral Neuroscience*, *128*, 283–303. doi:10.1037/a0035963

Webb, I. C., Antle, M. C., & Mistlberger, R. E. (2014). Regulation of circadian rhythms in mammals by behavioral arousal. *Behavioral Neuroscience*, *128*, 304–325. doi:10.1037/a0035885

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