Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Behavioral Sciences

Editorial overview: Time in perception and action

Warren H Meck and Richard B Ivry

Current Opinion in Behavioral Sciences 2016, **8**:vi–x

For a complete overview see the Issue

http://dx.doi.org/10.1016/j.cobeha.2016.03.001

Warren H Meck

Department of Psychology and Neuroscience, Duke University, Durham, NC, USA
e-mail: whmeck@duke.edu

Warren Meck is a professor of psychology and neuroscience at Duke University. His research is focused on the behavioral, pharmacological, and electrophysiological aspects of time perception. He has been involved in the development of an information-processing model of interval timing (Scalar Timing Theory), a neurobiological model of interval timing (Striatal Beat Frequency model), and a mode-control model of counting and timing. In recognition of this work, Prof. Meck has received an Alfred P. Sloan Foundation Research Fellowship in Neuroscience and a James McKeen Cattell Sabbatical Award. He is a founding editor of the journals Timing & Time Perception and Timing & Time Perception Reviews.

Richard B Ivry

Department of Psychology and Helen Wills Neuroscience Institute, University of California, Berkeley 94720-1650, USA
e-mail: ivry@berkeley.edu

Rich Ivry is a professor of psychology and neuroscience at the University of California, Berkeley. He directs the Cognition and Action lab, using various tools of cognitive neuroscience to explore human performance in healthy and neurologically impaired populations. Professor Ivry has a long-standing interest in the cerebellum, seeking to understand the role of this subcortical structure in skilled movement, timing, and, through its interactions with the cerebral cortex, cognition. In recognition of this work, he has received the Troland Research Award from the National Academy of Sciences and the William James Fellow Award from the Association for Psychological Science. He is a co-author of Cognitive Neuroscience: The Biology of the Mind, a textbook that has helped train a generation of students, and serves as an associate editor for the Journal of Cognitive Neuroscience.

A New York Academy of Sciences conference organized by John Gibbon and Lorraine Allan in 1983, with the subsequent volume *Timing and Time Perception* [1], was pivotal in bringing together researchers from many disciplines who shared a common interest in temporal processing. Over the past three decades the field has grown substantially, with significant advances arising from human and animal research, employing the full range of methods in cognitive neuroscience, neurobiology, and computational modeling. Many research groups have pursued the 'Holy Grail' for this field, what Matt Matell has referred to as "the neural structures, activity patterns, and computational processes that serve as the 'internal clock'" [2] — p. 209. Others have pushed in a different direction, arguing that the concept of an internal clock is misleading, emphasized instead that we need to appreciate how temporal processing is an emergent property of neural dynamics and state representations of temporal patterns [3]. The aperture of the 'timing' spotlight has also increased in interesting and unexpected ways, moving well beyond tasks that examined how well people perceive and produce intervals. Timing research now encompass a diverse set of tasks: Behavioral studies look at questions such as how attention entails temporal predictability or how time is distorted in multisensory integration. Physiological methods are employed to ask how time may be encoded in the ramping activity of neurons or to ask how temporal representation may emerge through the entrainment and coincidence detection of patterns of endogenous oscillations.

This issue of the *Current Opinion in Behavioral Sciences* continues the mission of promoting an interdisciplinary approach to the study of timing and time perception. While there have been a number of important books, reviews, and special issues dealing with timing in the past few years [4–14], this volume brings together contributions that provide a broad portrait of the breadth of questions and methods currently being pursued in the field. As the term 'opinion' in the journal's title suggests, the special issue is not designed to provide encyclopedic coverage of all topics or points of view. Rather, we set out with the goal to take stock of the state of affairs in key domains of timing research, as well as to highlight areas that we anticipate will be prominent in studies of temporal processing over the next decade.

A major question that has been posed, both from within as well as from outside the field, is the impact that a better understanding of the neural mechanisms of timing might have on its contributing disciplines. To take one example, in the 1984 New York Academy of Sciences volume, a number of papers focused on information-processing models, work in which the theorists were (happily) disinterested about whether and how hypothesized pulse accumulations were carried out biologically. As evident in the current

Table 1

Listing of topics, subtopics and authors.

Cognition and psychophysics	Interval representation	Bruno and Cicchini
		De Corte and Matell
		Droit-Volet
		Fortin and Schweickert
		Hartcher-O'Brien, Brighouse and Levitan
		Kirkpatrick and Balsam
		Matthews and Gheorghiu
		Murai, Whitaker and Yotsumoto
	Multisensory representation	Allman and Mareschal
		Bausenhart, Bratzke and Ulrich
		Elliott, Chua and Wing
		Iversen and Balasubramaniam
		Lake
		Linares, Cos and Roseboom
		Rohde and Ernst
		Shi and Burr
		van Rijn
Computational models	Psychological	Addyman, French and Thomas
		Balcı and Simen
		Freestone and Church
	Neurobiological	Buhusi, Oprisan and Buhusi
		Hardy and Buonomano
		Hass and Durstewitz
Neural mechanisms	Cortical	Coull, Vidal and Burle
		Hussain Shuler
		Kononowicz and Penney
		Kotz, Brown and Schwartze
		Merchant and Yarrow
		Narayanan
		Yin, Terhune, Smythies and Meck
	Subcortical	Agostino and Cheng
		Breska and Ivry
		Doyère and El Massioui
		Harrington and Jahanshahi
		Johansson, Hesslow and Medina
		Lusk, Petter, MacDonald and Meck
		Raghavan, Prevosto and Sommer
	Oscillatory	Gupta and Chen
		Herbst and Landau
		Tsilionis and Vatakis
		van Wassenhove
		Wiener and Kanai

volume, these models remain relevant, but have been greatly modified by studies using neuroscientific methods. Moreover, the field of timing research may be a model case of how insights from different methods of study are informative in shaping research questions asked at other levels of analysis. Information-processing models have been influential, not only in generating quantitative predictions that can be studied behaviorally, but has also inspired neurobiologists to think seriously about how the brain might implement a pacemaker or accumulator, or how the functional properties of such processes might emerge from alternative neural mechanisms [15–19].

The 42 contributed papers available in the special issue can be usefully organized into three main topics, each with two or three prominent subtopics: First, Cognition and Psychophysics, with a focus on interval representation and multisensory integration; second, Computational Models and how these can be applied to account for psychological or neurobiological representations; and third, Neural Mechanisms, including studies of temporal processing at the cortical or subcortical level, or through the operation of oscillatory processes as outlined in Table 1.

The study of time perception and production has a long and storied history in psychology. Indeed some of the earliest psychophysical studies focused on the veridicality of our sense of the passage of time and the specious present [20]. Interval representation continues to be a core problem in the field, and continues to motivate sophisticated experimental work. Many papers in this volume follow in this tradition. The function of the brain is to generate and control the behavior of the organism, i.e., coordinating the movement of multiple effector systems all in the service of achieving the goal of being in the right place at the right time. Such control requires