

Timing & Time Perception Reviews: Opening the Door to Theoretical Discussions of Consciousness, Decision-Making, Multisensory Processing, Time Cells and Memory Mapping ... to Name But a Few Issues of Relevance to Temporal Cognition

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The journal *Timing & Time Perception* (Brill Publishers) was initiated with the realization that the study of 'timing and time perception' is growing exponentially with interest from fields as diverse as cognitive science, computer science, economics, philosophy, psychology, robotics, and neuroscience ... to name just a few. As with any scientific endeavor, once a sufficient empirical base has been established it becomes both necessary and desirable to support such a rapidly growing enterprise with a platform for publishing integrative and multidisciplinary reviews. We are pleased to announce that *Timing & Time Perception Reviews* (a joint publication of the University of Groningen and Brill Publishers) is being launched as a diamond open-access journal with that goal firmly in mind. Some of the highlights of the inaugural issue are presented in our editorial along with examples of the types of ideas we would like to see developed in future submissions to the journal.

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I Editorial

Numerous reports have highlighted the importance of the detection of synchrony in neural oscillations related to both interval timing and consciousness (Allman & Meck, 2012; Matell & Meck, 2004; Smythies, Edelstein, & Ramachandran, 2012, 2014a, b). The detection and integration of neural synchrony is a fundamental property of brain areas such as the claustrum and striatum – which receive significant input from cortical, hippocampal, and

thalamic structures and have been related to consciousness and temporal processing (e.g., Buhusi & Meck, 2005; Gibbon, Malapani, Dale, & Gallistel, 1997; Smythies, Edelstein, & Ramachandran, 2012, 2014; Wittmann, Burtscher, Fries, & von Steinbüchel, 2004; Yin & Meck, 2014). This high degree of convergence allows these brain areas not only to serve as coincidence detectors of converging input, but also to cooperate in the synchronization of reverberating claustrum-cortical and cortico-thalamic-basal ganglia circuits. The idea of a centralized hub with a set of distributed networks has

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been used to investigate the abstract properties of consciousness and time perception as well as temporal illusions and intersensory processing (e.g., Allman, Yin, & Meck, 2014; Gu, van Rijn, & Meck, 2015; Merchant, Harrington, & Meck, 2013; Smythies, 2003; van Rijn, Gu, & Meck, in press). Moreover, such proposals are relevant to the understanding of neural mechanisms involved in decision-making, embodiment, multisensory processing, and the time–consciousness debate (e.g., Dainton, 2011, 2013, 2014; Droege, 2009; Förster-Beuthan, submitted; Hoerl, 2008, 2013; Indraco, Spence, Vatakis, & Harrar, in press; Meck, Doyère, & Gruart, 2012; Namboodiri, Mihalas, & Shuler, 2014; Tucci, Buhusi, Gallistel, & Meck, 2014; Vatakis & Ulrich, 2014; Wittmann & van Wassenhove, 2011). This emphasis on centralized “clocks” and cognitive control is in contrast to recent studies that have indicated the importance of temporal specificity in perceptual learning and have related these findings to the dynamics in the high-dimensional states of local neural networks – thus, reducing the need for core timing mechanisms (e.g., Bueti & Buonomano, 2014; Goel & Buonomano, 2014; Karmarkar & Buonomano, 2003, 2007). Future experiments and theoretical developments will be needed in order to resolve these issues and Timing & Time Perception Reviews will endeavor to be at the forefront of these debates involving consciousness, temporality, decision-making, audiovisual processing, and the integration of duration and rate at both local and more centralized levels of analysis (e.g., Allman, Teki, Griffiths, & Meck, 2014; Brighouse, Hartcher-O’Brien, & Levitan, 2014; Lloyd & Arstila, 2014; Vatakis & Spence, 2011).

The debate concerning local versus distributed or specialized timing mechanisms (Ivry & Spencer, 2004) leads quite naturally to the issue of how crucial temporal processing is to perception and cognition. Eagleman and Pariyadath (2009) were able to address this question by observing that the immediate repetition of a stimulus reduces its apparent duration relative to a novel item, thereby showing that subjective duration is a ‘general-purpose’ signature of coding efficiency. Recent work on repetition suppression suggests that it results from suppressed cortical responses to repeated stimuli, arising from neural adaptation and/or the predictive coding of expected stimuli. The review by Matthews, Terhune, van Rijn, Eagleman, Sommer, and Meck (2014) presented in this issue summarizes the various theoretical issues and uses the recent neurobiological findings of Terhune, Russo, Near, Stagg, and Kadosh (2014) showing individual differences in GABA-mediated cortical inhibition to explain the effects of repetition suppression on time perception. The conclusion is that the activity of cortical

neurons is modifiable by recurrent networks are affected by local GABA levels. These local networks contribute to a centralized process used to integrate across stimulus modalities, thereby allowing for the encoding of duration, number, and rate by a common mechanism as outlined in the excellent review by Brighouse, Hartcher-O’Brien, and Levitan (2014).

The distinction between the psychological and neural mechanisms underlying prospective and retrospective temporal judgments has recently been aided by the development of a unified approach involving a fading-Gaussian activation model of interval timing (French, Addyman, Mareschal, & Thomas, 2014). Future advancements on this topic will likely benefit from the identification of hippocampal neurons that fire at successive moments in temporally structured experiences (e.g., MacDonald, Lepage, Eden, & Eichenbaum, 2011 – for a review see Eichenbaum, 2014) and dorsal striatal neurons that fire at the time of an expected event such as the delivery of reinforcement (e.g., Matell, Nicolelis, & Meck, 2003 – for a review see Coull, Cheng, & Meck, 2011). These hippocampal and striatal “time cells” appear to be part of separate, but interactive neural networks that are able to encode and track the temporal order and durations of events, respectively. Moreover, it has recently been proposed that hippocampal “time cells” are primarily involved in retrospective temporal judgments where the past sequence of events is reconstructed in order to determine the durations of specific events (MacDonald, 2014). In contrast, striatal “time cells” are considered to be involved in prospective temporal judgments where the anticipation of when an event will occur guides temporally controlled patterns of behavior (e.g., Matell & Meck, 2004; Meck, Penney, & Pouthas, 2008). These different types of “time cells” and their differential roles in interval timing and memory for elapsed time have recently been reviewed by MacDonald, Fortin, Sakata, and Meck (2014) in which the importance of a unified model of prospective and retrospective timing such as that proposed by French et al. (2014) in the inaugural volume of Timing & Time Perception Reviews is discussed.

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