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Sleep, circadian rhythms and interval timing: Evolutionary strategies to time information

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Abstract

Sleep, circadian rhythms, and interval timing are evolutionary well-conserved functions that are widely shared throughout the animal kingdom. A crucial property of the brain is to make use of internal clock mechanisms (e.g., circadian) to locate events in time. From a neurobiological and computational point of view, clock mechanisms can be seen as strategies that involve information processing of internal biological states at different time scales (Tucci, 2011; Tucci et al., 2014).

The coordination between temporal information processing and internal physiological responses maintains homeostasis in many biological domains. For example, sleep is a genetically and epigenetically regulated phenomenon that can be mathematically modelled by, at least, two fundamental processes, a homeostatic process and a circadian process. The homeostatic process of sleep depends on the previous wakefulness, representing the pressure for sleep since last sleep episode. The circadian process dictates the timing of sleep, it is a self-sustained periodic mechanism and it develops with approximately 24 hours, cell-autonomous, oscillations. Thus, the distribution of sleep over 24 hours results from the combination of these two processes.

Moreover, the ability to understand and perform in time is also realised within seconds-to-minutes intervals (e.g., interval timing). Interval timing represents a cross-species crucial property of many cognitive processes; interestingly, this short timing ability varies with the time of day, and it has been shown that sleep enhances the consolidation of timing learning. Furthermore, we have observed that mouse performance is modulated by a sleep inertia-like effect (Maggi et al., 2014).

To understand the interplay between sleep homeostasis, circadian biological rhythms and interval timing it is mandatory to address specific questions on the genetic and epigenetic regulatory mechanisms that are associated with these functions. To address these questions, I will present our recent work which has been focused in: (i) understanding whether monoallelic versus biallelic epigenetic mechanisms exert a specific role in sleep and sleep-related timing functions (Lassi et al., 2012; Tinarelli et al., 2014), (ii) understanding how circadian rhythms and sleep-wake mechanisms modulate various cognitive processes such as

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interval timing, temporal uncertainty and risk assessment, (iii) understanding whether clock genes regulate sleep homeostasis and cognitive timing, by investigating these functions in mouse clock mutants.

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Keywords: Circadian; Sleep; Interval timing; genes

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