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Programming human sleep/wake patterns in the real-world: emergent patterns from simple rules

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Maintaining regular and sufficient sleep is important to many aspects of human health. Mathematical models of human sleep/wake patterns have typically been trained against highly regular, prescribed schedules in healthy individuals under laboratory conditions or idealized versions of real-world work schedules. Consequently, most models are deterministic and do not capture measured inter-individual variability or intra-individual variability in sleep/wake timing and duration. We extended a mathematical model of human sleep/wake patterns to incorporate aspects of real-world schedules. The model was based on the neurophysiological circuits in the brainstem and hypothalamus that regulate sleep/wake patterns, including the circadian clock and its response to light. Three simple additions to the base model were made: (i) Constraints on sleep times, representing weekly work and social constraints; (ii) Self-selection of light patterns, including exposure to natural light sources if awake during daytime and artificial light sources if awake during nighttime; (iii) Day-to-day variability in sleep onset tendency, reflecting tendency to persist with engaging behaviours (or to ruminate in insomnia) close to bedtime. From these simple rules emerged key quantitative properties of real-world sleep patterns, including: (i) Social jet-lag (i.e., mismatch between weekday and weekend sleep times); (ii) Inter-individual and intra-individual variability in sleep timing and duration, including pathological cases such as insomnia; and (iii) Challenges adapting to certain phases of rotating shift-work schedules. These findings indicate that, although human behaviour is highly complex, individual-level and population-level sleep/wake patterns can be largely recapitulated by simple rules applied to physiologically based models.

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