Sleep Stage Continuity And a Derived Sleep Wake Transition Model
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Abstract—During normal sleep different sleep stages follow a well described sequence from wakefulness, light sleep, deep sleep and REM sleep. And the sequence is repeated several times per night. In patients with sleep disorders the percentages of time spent in sleep stages is disturbed and more often the sequence of sleep stages is disturbed. The disturbance, experiences as awakenings from sleep, or fragmented sleep, can be described by an analysis of sleep continuity. Based on normal sleep continuity a sleep wake transition model had been derived and described. The parameters of the model may serve to characterize normal and disturbed sleep as well. The usefulness of these parameters needs to be proven in subsequent clinical studies.

I. INTRODUCTION

The technique of sleep recording and the definition of sleep stages has been given in recommendations compiled by Rechtschaffen and Kales (1968). Sleep stages were defined in this recommendation as wake, stage 1, 2, 3, 4, and completely different as REM with rapid-eye-movements. Sleep stages are evaluated in consecutive 30-s epochs resulting in a sleep profile. In normal sleep, the stages follow a structured sequence starting with wake, then light sleep with stages 1 and 2 (light sleep), followed by deep sleep with stages 3 and 4, and then followed by REM sleep. This sequence is called a sleep cycle with a typical duration of 90-110 min. A normal night consists of six sleep cycles where the proportion of deep sleep decreases from the beginning to the end of the night and the proportion of REM sleep increases. The usual clinical reporting is the calculation of the percent of time spent in a specific sleep stage. Normal values have been reported for these percentages. In summary, about 50-60% of time is spent in light sleep, 15-20% of time is spent in deep sleep, 20-25% is spent in REM sleep, and 5% or less is spent in wakefulness. Sleep stage transitions and arousals may be reported in addition to better characterise disturbed sleep. Definitely this is not enough to characterize sleep disorders.

II. METHODS OF MODEL DEVELOPMENT

In order to obtain a new quantitative description, we applied methods of statistical physics to the sleep profiles (Lo et al. 2002). The duration of the joined sleep stages (defined as light, deep, and REM sleep combined) followed an exponential distribution with a characteristic time scale \( \tau \).

\[
p(t) \sim \exp(-t/\tau) \quad \text{with} \quad \tau = 22 \pm 1 \text{ min}
\]  

(1)

In contrast, the duration of short wake periods during sleep follows a completely different distribution. They followed a scale-free power-law distribution.

\[
p(t) \sim t^\alpha \quad \text{with} \quad \alpha = 1.3 \pm 0.1
\]  

(2)

Based on these results we developed a stochastic random walk model with added forces pulling the walker towards sleep (Lo et al. 2002).

III. RESULTS

The model shows a good agreement with data. It suggests that the differences in the underlying laws for the dynamics of wake and sleep stages arise from the constraints on the number of stages in the sleep-wake system. We assumed that there are completely different neural systems involved in the regulation of sleep stages and wakefulness. We do not think that there is just a switching between wakefulness and sleep states in the same neurons, but different parts of the brain are involved (Penzel et al. 2003). To our surprise we did not find different laws for the distribution of REM sleep and non-REM sleep durations. This leads to the speculation that both components of sleep with different physiological functions still are regulated in the same way by central sleep regulation. When investigating the distribution of sleep stages in patients with sleep apnea, we found the same laws. This confirms the universality of this regulation even if sleep apnea is a disorder with severe sleep fragmentation (Lo et al. 2004). Only the actual values of \( \alpha \) and \( \tau \) were different.

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REFERENCES

