APPROXIMATE ENTROPY BASED ON ISOMETRIC TREMOR: RELIABILITY AND OPTIMAL SAMPLING FREQUENCY

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INTRODUCTION

Approximate entropy (ApEn) [1] calculated from isometric tremor torque time-series provides additional information of the neuromuscular system, compared to that obtained from the traditional analysis (standard deviation (SD) or spectral analysis) [2]. The ApEn value is determined by the complex pattern of the neuromuscular system, decreases with pathology as e.g. Parkinson's disease, and reflects the severity of the disease [2]. However, ApEn can be biased due to both over- and under sampling, when calculated from continuous biological signals as e.g. isometric tremor. Methodological issues such as optimal sampling frequency and reliability of the method has not previously been assessed.

The aims of this study were to examine the significance of the sampling frequency for the ApEn values and to examine the test-retest-reliability of ApEn calculated from isometric tremor torque time-series [3].

METHODS

Eighteen healthy young subjects (13±3 years, mean ± 1SD) performed four trials of attempted steady isometric submaximal contractions with the ankle dorsal- and plantarflexors at two different days separated by seven days. While seated, contractions were performed with real-time visual feed back at target torques of 0.1 and 0.3 Nm/kg body weight (dorsalflexion) and 0.3 and 0.5 Nm/kg body weight (plantarflexion). Each trial consisted of five 13-s contractions, separated by 60-s pauses. All torque signals were sampled at 1 kHz.

The ApEn algorithm is based on embedding vectors constructed of successive observations from the torque time series [1]. The ApEn algorithm was studied and the optimized frequency was defined as twice the highest measurable Fourier high-pass filter frequency that kept observations in the torque time-series within the range of ± the measurable noise. ApEn was calculated to examine motor-system regularity from torque time series down-sampled to 30 Hz (optimized) and 100 Hz (the traditionally used). The biological day-to-day variation was quantified using intra-class correlation ($ICC_{3.1}$) coefficients (relative reliability) and standard error of measurement (SEM) (absolute reliability).

RESULTS AND DISCUSSION

Frequency analysis demonstrated that the highest measurable frequency in the torque time-series to be confidently considered biological varied between 12 and 15 Hz. Thus, an optimized sampling frequency of 30 Hz is suggested according to the Nyquist rate. The ApEn value decreased indicating increased regularity as the torque time series sampling frequency increased (Figure 1). Increasing sampling frequency reduces the average amplitude difference between to successive observations in the torque time-series. Therefore, the embedding vectors become more homogeneous in the sense that it is more likely that they only differ by the magnitude of the noise. We propose that this phenomenon is oversampling, which reduces the ApEn value dependency on the biological system. Thus, the optimal sampling frequency is obtained when the average amplitude difference between successive observations, mainly reflects changes in the biological system.

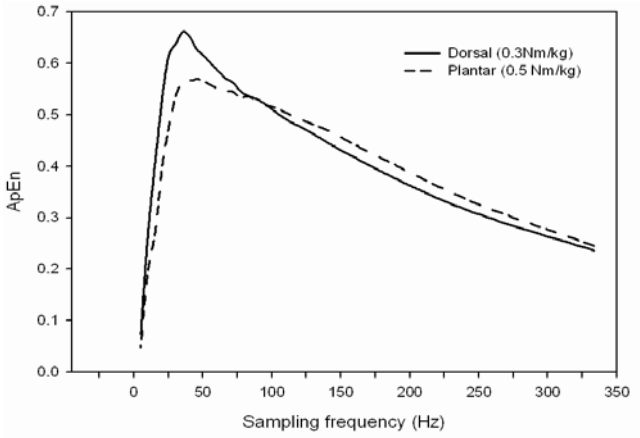

Figure 1: ApEn values in a representative subject versus sampling frequency.

The relative reliability of the torque time-series down-sampled to 30 Hz varied from fair to substantial ($0.559 \leq ICC_{3.1} \leq 0.897$), and down-sampled to 100 Hz from less than fair to substantial ($0.360 \leq ICC_{3.1} \leq 0.858$). In general, the relative reliability ($ICC_{3.1}$) was highest when calculated from the 30 Hz torque time-series. The absolute reliability was generally high. That is, the SEM was low and ranged from 6 to 14 % of the mean test-retest ApEn values.

CONCLUSIONS

We propose that an optimal sampling frequency exists for ApEn calculations, which will increase the sensitivity for biological system-changes, reduce adverse effects of random noise, and ensure that biological information in the signal is preserved. We recommend estimating this frequency using a high-pass filter-method. The biological day-to-day variation of ApEn calculated from isometric tremor torque time series proved to be reliable in healthy young subjects.

REFERENCES

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