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EEFECT OF SAMPLE FREQUENCY AND FILTER FREQUENCY ON APEN VALUES FOR ISOMETRIC FORCE RECORDS: TOWARDS A GOLD STANDARD

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INTRODUCTION

It is of use to an investigator to be able to quantify the complexity of a finite physiological time series in order to gain a better understanding of complex control systems [e.g. 1]. For example, changes in the complexity of the signal may occur at the onset of degeneration [2] and may therefore be of use as a tool in the early detection of degeneration and disease. Measures such as ApEn [3] have been widely used to quantify such signal complexity and so distinguish between different patient groups. ApEn has also been used widely to quantify changes in the complexity of fluctuations in the force record arising from isometric contractions [e.g. 1]. However, there is currently no standard approach to the sampling and processing of data prior to the ApEn analysis process.

It seems logical that the sampling frequency chosen would be of importance since it has an effect on signal characteristics that alter ApEn values [3, 4] Studies on the steadiness of isometric muscular contractions have collected data at high frequencies, and subsequently down-sampled to frequencies as low as 140 Hz [e.g. 1]. This also seems to be the case when choosing the filter cutoff frequency, for example frequencies as low as 25.6 Hz have been used to filter isometric force data [e.g. 1]. Though most signal power, in such data, is generally below 12 Hz, tremor oscillations have displayed frequency peaks up to 40 Hz [5]. It has been suggested that during isometric contractions there are frequencies components n the 20-25 Hz range [6]. This would mean cut-off frequencies as low as 25.6 Hz or 30 Hz may remove parts of the signal that are due to physiological processes.

The length of a data series (which is determined by both sample rate and collection time), the algorithm used to remove non-steady state sections of the contraction history, the filter characteristics, and signal noise estimation are all likely to have an effect on the ApEn value [3]. Though studies use varying methods of signal processing, results are often compared without identifying whether these factors alter the outcome of the data. Therefore the aim of this study was to assess changes in the ApEn values of physiological time series data brought about by sampling and post-processing changes.

METHODS

Two groups of neurologically healthy subjects were recruited; a group of younger subjects aged from 18 to 25 years old (n = 12; range mean = 23 ± 4 years; seven females and five males), and a group of older subjects from 65 to 75 years old (n = 11; mean = 67 ± 5 years; six females and five males). All subjects gave written informed consent. All experimental procedures were approved by Aberystwyth University Research Ethics committee.

The subjects' non-dominant hand was placed in a custom made rig. The load cell (PW6CMR HBM UK Ltd, Harrow, UK) and thumb rest were positioned so that the load cell was level with the lateral side of the proximal inter-phalangeal joint with the angle between thumb and index finger being approximately 80° when the finger was in contact with the load cell. Subjects performed three maximum isometric contractions lasting for approximately three seconds. The maximum force achieved across the three trials was used as the subjects' maximum voluntary contraction (MVC) which was then used to compute, for each individual, target force levels at varying percentages of maximum. Subjects produced isometric contractions at 5%, 10%, 25%, 50%, and 75% of their maximum for ten seconds by targeting a force displayed on a computer monitor in a Labview 8.2 environment. The order of the contractions performed was randomised. A one minute rest was given between lower efforts and three minutes rest was given for 50% and 75% of max effort. A minimum variance criterion was used to select a window of three and five seconds for analysis, the whole data were also analysed omitting the first four seconds and last second of data to allow for the initial transient period and possible premature cessation.

The signal was sampled with no force exerted on the sensor and also with a constant load in order to gain an estimate of the noise in the system (Figure 1). Although electrical noise was not identified in this signal it was found in some of the trials and was therefore filtered out using 49.0 Hz to 51.0 Hz 8th order notch filter. The force signal was sampled at 1200 Hz and filtered using a zero lag Butterworth filter with varying cutoff frequencies. ApEn was used to assess the force structure using the method described in [3]

RESULTS AND DISCUSSION

Several different processing conditions were applied to the force data in post-processing to answer various questions:
1) What frequencies are present in the signal?
Frequency spectral analysis of the noise (estimated from trials with no load on the force sensor) and the trials showed changes in the signal during isometric contractions above frequencies of 30 Hz that appear not to be due to noise. This is most prominent in isometric contractions at 50% of MVC and greater with increasing power above 30 Hz with increasing MVC level.

2) What happens if the sampling frequency is reduced?
Decimation of the signal was carried out to 30 Hz, 100 Hz, and 140 Hz. Decimation changed values of the ApEn value to show patterns that were almost opposite to the undecimated data (see figure 2). This change in pattern became more extreme the lower the data was decimated to so that it resulted in higher ApEn values for lower % MVC and lower ApEn values for the higher % of MVC (Figure 1).
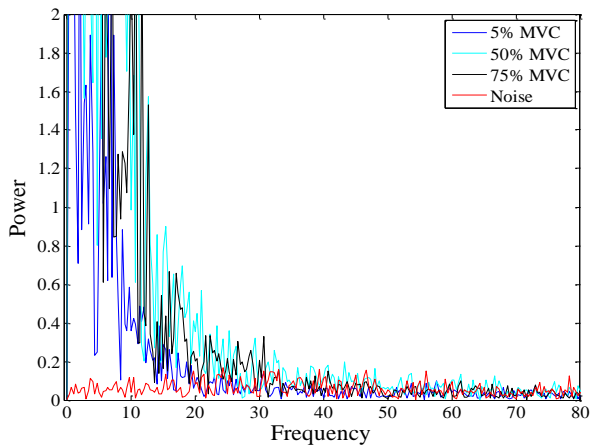
Figure 1: Frequency spectra of isometric forces recorded at different loads and loaded noise signal.

3) Are the effects of reducing the sample frequency due to having fewer data points or is it to do with the frequencies that are captured?

Analyses were performed using the original sampled data (1226 Hz) but truncated using a minimum variance window to capture data with the same number of data points to those analysed during down sampling (e.g. truncating the 1226 Hz signal to 90 data points would be equivalent to down sampling to 30 Hz for 3 seconds). The pattern of ApEn results were similar (though the actual values were lower which would be expected) for shorter time series sampled at the same high frequency, but the pattern changed when the data was decimated (see figure 2). Truncating the data at varying positions across the data to 300 data points (equivalent of 3 seconds at 100 Hz) without using the minimum variance window also resulted in patterns similar to the undecimated truncated signal (Figure 2). This suggests that it is not the number of data points analysed that causes the change in the relationship between the mean ApEn values for the different effort levels and age groups but the sample frequency.
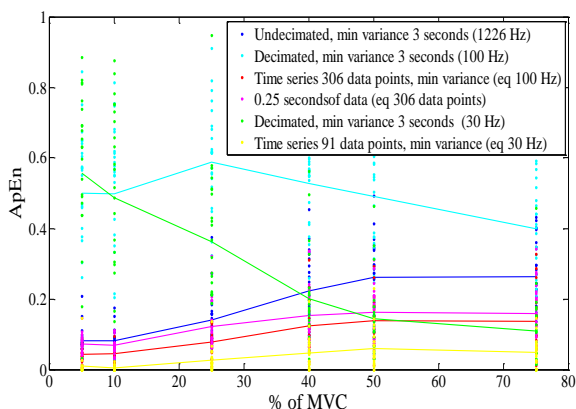

Figure 2: ApEn results for varying decimation and sample sizes against undecimated data. (80 Hz filter cutoff.)

4) What is the effect of filtering at different frequencies?

Filtering with low-pass cutoff frequencies of 25.6 Hz, 30 Hz, 60 Hz, 70Hz, 80Hz, 90Hz and 100 Hz were used. As filtering frequencies were lowered the ApEn values decreased across the levels of MVC. The trend remained similar using the different filter cutoff frequencies (Figure

3). The decimated force signal was also filtered using the same cutoff frequencies, the results showed a similar pattern with little alteration in the trend but shifts observed to lower ApEn values the lower the filter cutoff frequency used. However, the frequency spectral analysis of the force signal did show power in frequencies above 30 Hz (Figure 1) suggesting that filtering below this level may not be appropriate.
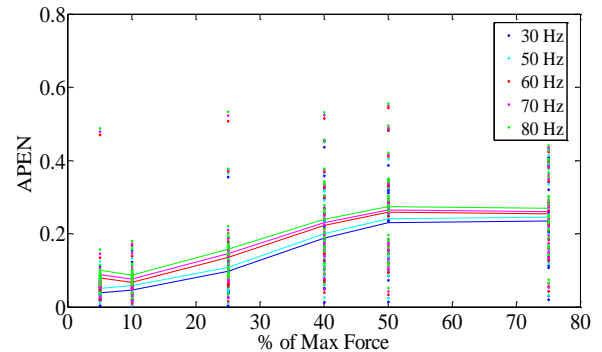

Figure 3: ApEn results for varying filter cutoffs (Sampled at 1226 Hz).

It would appear that any signal capture or processing choice that affects the frequencies captured has some affect on the relationship in ApEn values across effort levels for the two age groups. Higher frequencies are present in the force spectrum particularly at 50% and 75% MVC contractions suggesting a need for higher cut-off rates than those used previously. These high frequency fluctuations may be due to increased neuron firing frequencies at higher force levels. These frequencies are often considered to be damped or smoothed at the neuromuscular junction and by muscle-tendon interactions; however tendon length variability and stiffness between subjects has been shown to be large [7].

CONCLUSIONS

Sampling rates and filter cut-offs have been shown to affect the ApEn values calculated for isometric force data. It is possible that physiological frequencies are being filtered out when using low filter cut-offs and down sampling at or below 30 Hz, and these have been shown to have an affect both on the ApEn values calculated and the relationship between mean values for different effort levels and age groups. Previously, little standardization or guidance in post the processing of such data; therefore future work should consider the most appropriate sample and filter rates by reference to the frequency spectra.

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