Measuring complexity in EEG in response to speech stimuli

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1. Introduction and Background:

- Early diagnosis of hearing conditions such as central auditory processing disorder (CAPD) plays a crucial role in the future development of a child with this condition as it impacts on their speech.
- Conditions such as CAPD cannot be identified with standard hearing tests as in a noise free environment the child can understand speech and hear tones, but as the environment becomes increasingly noisy, understanding becomes increasingly difficult for them.
- EEG signals in the brain are produced by the non-linear interactions of electrical signals in the brain. When sound enters the ear an auditory evoked potential (AEP) is produced and this in incorporated into the overall EEG signal.
- Due to these non-linear interactions, EEG signals are complex in nature and as such complexity analysis (such as multiscale entropy) can be used to detect changes in the signal in response to stimuli. This technique could be used as a non-invasive, objective auditory function test to assist in early diagnosis of conditions like CAPD.

2. Multiscale Entropy Analysis:

- Multiscale entropy (MSE) analysis is a form of complexity analysis developed by Costa *et al.* (1) that involves analysing complexity of a time series over many scale factors.
- Initially the time series is coarse-grained to produce the different scale factors. This procedure is described in figure 1A and involves averaging across vectors of varying length within the original time series.
- Sample entropy is then calculated by identifying matching vectors (within a tolerance r) of length m within the time series and then determining how many of those vectors still match at vector length m+1 (Figure 1B)

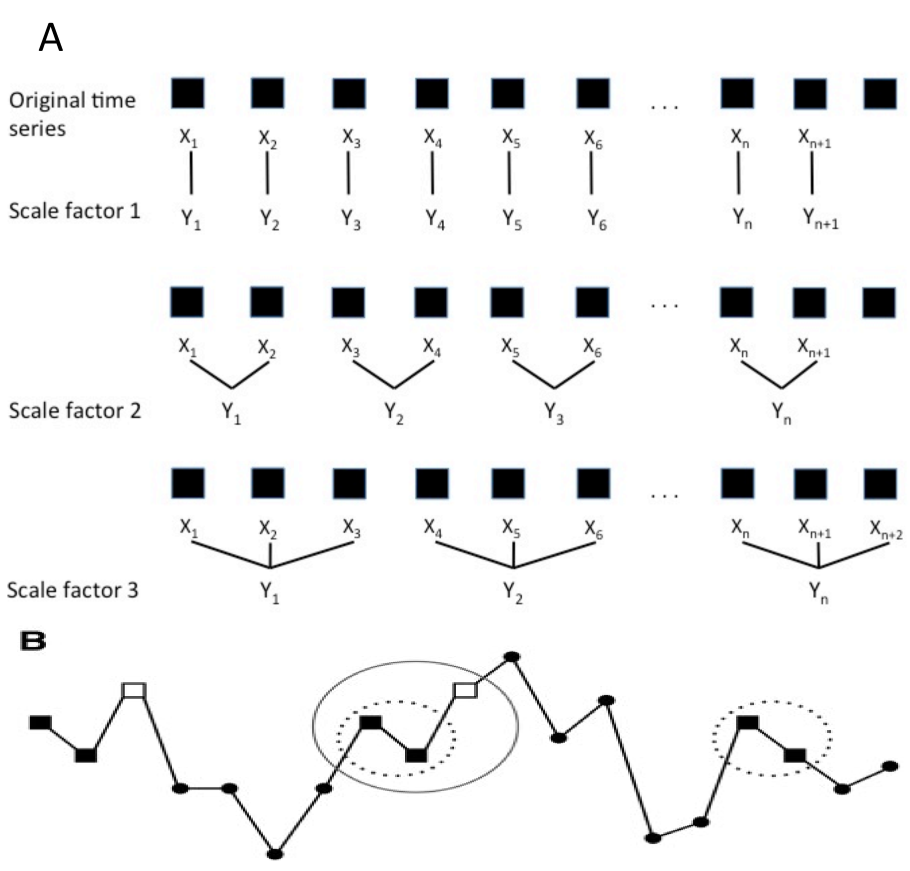

Figure 1: The coarse-graining procedure is shown in A. This involves averaging the original time series in non-overlapping windows of the same length as the scale factor. B shows how sample entropy is calculated (2). Initially Matching vectors of length m within a tolerance r is determined and then the number of these vectors that match at vector length m+1 is calculated before the negative natural logarithm is taken.

3. Case 1- Noise analysis:

- The MSE method was found to accurately characterise the sample entropy of white noise when compared to the analytical solution described by Costa *et al.* (Figure 2A).
- Analysis of various types of noise shows that underlying correlation (as seen in pink and brown noise) is required to produce increasing sample entropy over increasing scale factors and not just random fluctuations (as seen in white noise) (Figure 2B).
- This allows the technique to be used to analyse EEG data which is inherently noisy as white noise would not result in an increase in complexity index and other non-linear interactions or correlations in the data is required.

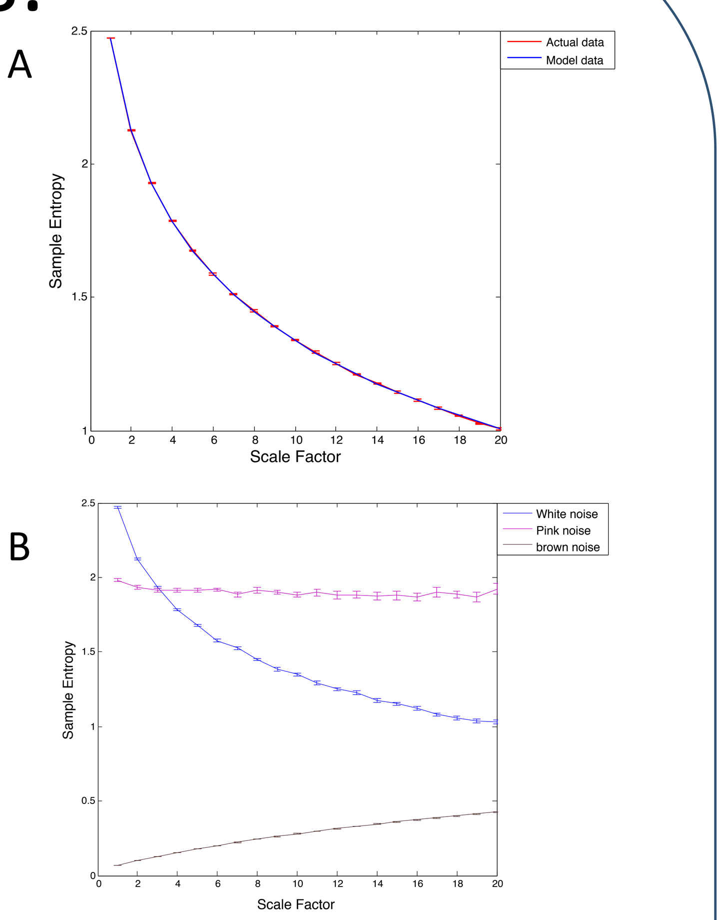

Figure 2: Multiscale entropy analysis was used to analyse the complexity of different kinds of noise. Figure A shows the complexity calculated by the method when compared to the analytical solution described by costa *et al.* Different kinds of noise were then analysed in figure B with increasing content of low frequency signals with white having the lowest and brown the highest content.

4. Case 2- Broadband analysis:

- A simulated AEP was produced using the model produced by Rønne *et al.* (3) in response to either a sinusoidal amplitude modulated tone or a speech file which was then added to an EEG signal at varying signal to noise ratios (SNRs).
- A signal to noise ratio of -10 ($p < 0.01$) was needed to detect a significant difference from an EEG signal without an added AEP for an AEP produced in response to a tone (Figure 3A) and -5 ($p < 0.01$) for an AEP produced in response to a speech file (Figure 3B).
- These SNRs are achievable in real EEG recordings and thus this technique has a potential use as a test for auditory function.
- Its potential could be improved by filtering the signal as it is known that information is carried at certain wavelengths depending on the signal and thus this could improve the SNR needed.

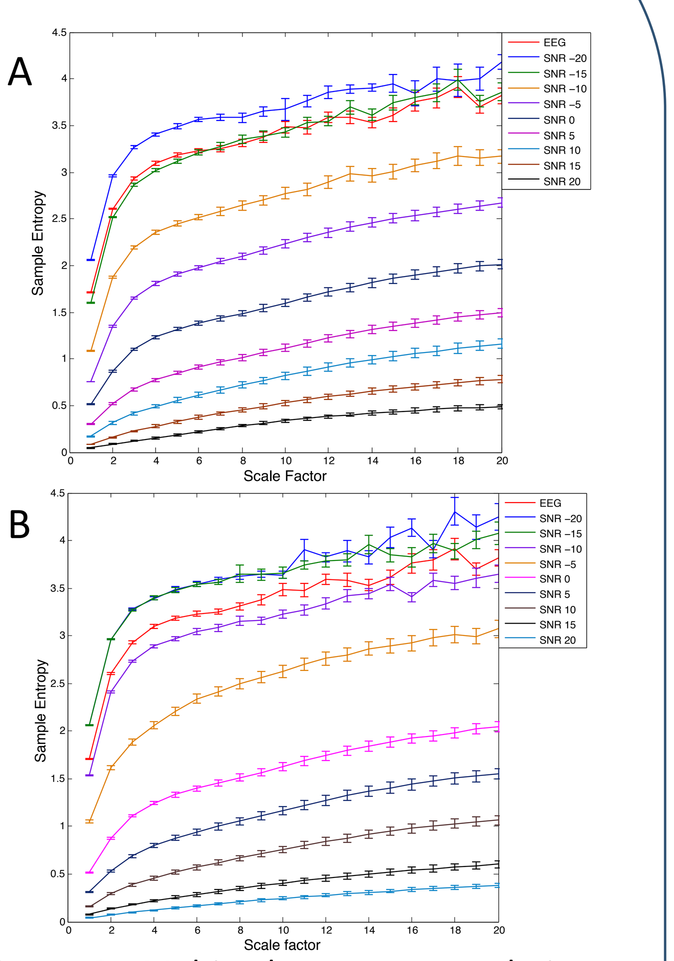

Figure 3: Multiscale entropy analysis was used to analyse the complexity of EEG signals after addition of a simulated AEP produced in response to either a sinusoidal amplitude modulated tone (figure A) or a speech file (figure B). This was also compared for varying signal to noise ratios.

5. Case 3- Narrowband analysis:

- Filtering of EEG data to remove noise from bandwidths outside those frequencies of interest resulted in an overall decrease in complexity.
- The SNR to detect a significant difference between EEG and that containing an AEP was found to be -20 for addition of an AEP produced in response to a tone ($p < 0.01$) (Figure 4A) and -5 for the addition of an AEP produced in response to speech ($p < 0.01$) (Figure 4B).
- There is a benefit in detecting a difference in signal complexity when filtering to improve the signal to noise ratio.
- However, to filter the data you have to specify a bandwidth of interest and thus information from outside this bandwidth is lost (along with noise).

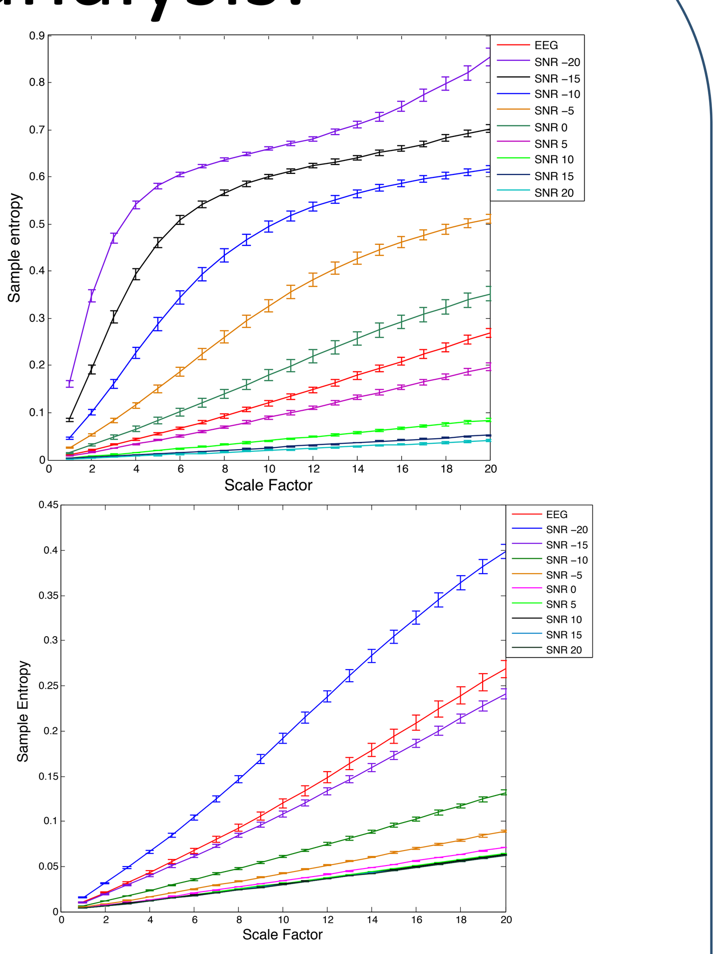

Figure 4: Multiscale entropy analysis was used to analyse the complexity of EEG signals after addition of a simulated AEP produced in response to either a tone (figure A) or a speech file (figure B) and after filtering with a Butterworth filter to remove noise from outside the bandwidths of interest. This was also compared for varying signal to noise ratios.

5. Conclusions:

- The MSE method was found to be effective at distinguishing EEG signal from EEG containing simulated AEPs at signal to noise ratios that would be reasonable in during a real recording.
- Future work should be done to utilise this method in the analysis of real EEG recordings containing AEPs to determine if this method could be used as a non-invasive, objective test for auditory function.

References

1. Costa *et al.*, Phys. Rev. Lett., 2002, **89**, 68.
2. Lu *et al.*, BRAIN, 2012, **121**, 1438.
3. Rønne *et al.*, J. Acoust. Soc. Am., 2012, **131**, 3903.

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