SPINDLE FILTER OPTIMISATION WITH RECEIVER OPERATING CHARACTERISTICS-CURVES

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Abstract: The automatic detection of sleep spindles can be accomplished with filter methods. The optimisation of filter characteristics is necessary to improve the performance of the detection. Raw EEG data were filtered with varying basebands in the frequency range of sleep spindles. The outputs were taken to calculate Receiver Operating Characteristics-Curves (ROC-Curves). The area under the ROC-curve (AUC) served as the only optimisation parameter. The maximum AUC had 0.962 square units. This result corresponded to a filter-function with edge-frequencies of 12Hz and 16.8Hz. The shown optimisation procedure is not limited to any number of free parameters. Solely data marked by an expert is needed. The ROC-curves can be further used to find a suitable detection-threshold for sleep spindles.
Keywords: sleep spindles, filters, ROC-curves

Introduction

Sleep spindles are important patterns seen in the sleep EEG. According to the rules of Rechtschaffen and Kales (R&K) [1] spindles have a frequency in the range from 12 – 14Hz. A sinusoidal appearance as well as a waxing and waning character are typical attributes. According to these characteristics, filter operations can be used to automatically detect spindles.

However, the frequency of sleep spindles is not as limited as the rules of R&K would imply. Varying specifications of spindle-frequencies can be found in literature. Extreme definitions cover frequencies from 10 – 18Hz. Nevertheless, the baseband of spindle-filters should not be too wide [2]. Therefore the filter characteristics must be optimised. Scoring information provided by experts can be used to solve this problem.

The measurement of more than one single resulting value raises the question, which one is important and should be optimised. A single quality parameter is needed to improve the result of the automatic spindle detection objectively. Summing, filter characteristics as well as the performance of a recognition system should be optimised with a single decision parameter.

It will be shown that the usage of ROC-curves combined with the scoring of an expert solves the problems mentioned. As an example, only the baseband of a spindle filter is optimised. However, this is not a limitation of the underlying principle of optimisation.

Materials and Methods

The used database consisted of 6 continuous EEG segments. Each cut-out had a duration of 7 minutes. The segments were taken from 2 subjects (EEG-channels F4, C4 and P4). The data were sampled at a rate of 102.4Hz. 291 sleep spindles were manually marked and contained 28457 samples. The segments were concatenated to form a total of 258048 sample points. All calculations were performed on a PC using Matlab.

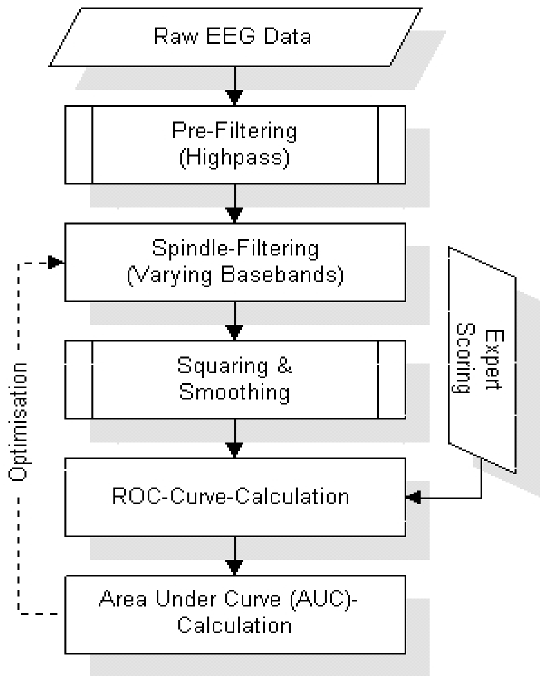

Figure 1: Flowchart of the optimisation procedure.

At first, the raw EEG-data were pre-filtered with a highpass filter of 1st order having a cut-off frequency of 2Hz (Butterworth characteristic). Next, the resulting signal was processed by using a 3rd order Chebycheff type 1 bandpass filter. This filter operation corresponded to the main spindle detection step. For the optimisation, the centre frequency was iterative varied in the 11.6-15.4 Hz range. Both cut-off frequencies were independently changed using a 0.2Hz stepwidth. The maximum bandwidth was therefore 10-18Hz, the minimal one ranged from 12.8-13.2Hz. The output of this filter process was squared to get a nonnegative detection function. Afterwards this function was smoothed using a 51-point hamming window. This calculation yielded a detection function with high amplitudes resembling sleep spindle activity in the EEG signal. All mentioned filter operations were performed in forward and backward direction to overcome the problems of phase distortion and group-delay. The filter functions were omitted here because of the rather specific sampling rate of 102.4Hz.

The ROC-curves were computed using the scoring information given by the expert. In short, the algorithm reads:

For each amplitude value of the detection function *do*:
  Take the amplitude value as threshold level
  Calculate the number of true and false positives
  Transform the absolute numbers to relative ones

The relative values were plotted in pairs (false/true) in the x/y-plane. This procedure yielded a curve in the range from exactly zero to one for both axis. Such a curve is called a ROC-curve. The area enclosed by a curve was calculated using a trapezoidal numerical integration algorithm. This value, which resembled the unique optimisation parameter, was computed for all different filter settings to determine the best variation of the parameters. An area of unity would indicate the optimal result, 0.5 the worst one. Figure 1 shows the flowchart of the basic calculation steps.

Results

The best achieved result, at least for the data under consideration, was a ROC-curve which enclosed 0.962124 square units. This corresponded to a spindle-filter having a baseband of 12-16.8Hz. The optimal centre frequency read 14.4Hz. Figure 2 shows the growing area beneath the ROC-curves by successive broadening of the bandwidth (stepwidth 0.4Hz) while keeping the centre frequency fixed at 14.4Hz.

Discussion

The resulting bandpass-filter with edge-frequencies of 12 and 16.8Hz entirely covered the commonly accepted range of spindle definitions. Whereas the lower boundary was met exactly, the upper one was significantly higher than the 14Hz recommended by R&K. Clearly the expert marked spindles due to his perception and knowledge. The filter was optimised for specific data and the decision strategy of the expert.

The ROC-curves reveal the overall performance of a detection method independent of any decision boundary. Having an area close to unity, the ROC-curve showed the nearly optimal indication of sleep spindles with filter methods. However, care should be taken if different curves do intersect. A generalised decision, which method is best, is then no longer possible.

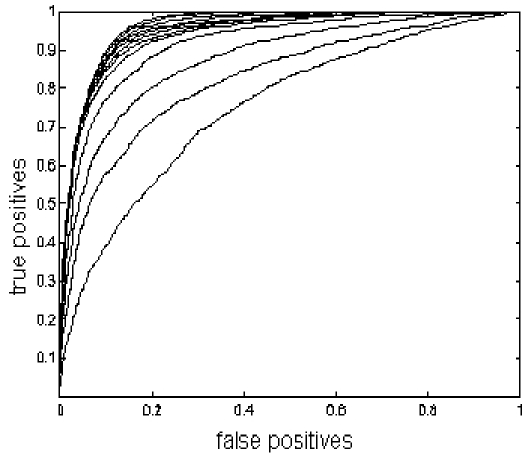

Figure 2: Plot of ROC-Curves calculated with different bandwidth settings of the spindle filter. Here, the baseband was successively broadened from 14.2-14.6Hz (lowest curve) to 10.8-18Hz. The maximum AUC (0.962) was calculated for the topmost curve (baseband 12-16.8Hz).

Conclusions

The results yielded a frequency band from 12-16.8Hz for the spindle-filter. The AUC value was 0.962, which means that we have at a chosen sensitivity of e.g. 95.9% a corresponding specificity of 84.2%. These percentages can be adjusted within limits by using other amplitude thresholds for the spindle detection.

The optimisation was achieved with only one parameter – the AUC – for the adjustment and evaluation of the method. Solely an expert scoring was needed. Therefore the shown procedure appears as a valid concept to avoid fixed definitions. The extension to many more free spindle-parameters and the finding of suitable thresholds for an automatic spindle detector can be easily done with the presented optimisation algorithm.

REFERENCES

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