ANALYSIS OF READING RELATED POTENTIALS BY COMBINING WAVELET DECOMPOSITION AND DYNAMIC TIME WARPing

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ABSTRACT: The problem of obtaining a reference signal for reading related potentials (RRPs) during reading tasks is here addressed. The classical procedure based on the calculation of grand-averages on a group of subjects is strongly affected by the high inter-subject variability, that becomes especially relevant when dealing with long-latency waves related to the cognitive functions. A Dynamic Time Warping procedure is applied to pairs of RRPs after a time-scale decomposition through wavelet transform. The multi-scale decomposition of the signal permits to optimize the time warping procedure to the different temporal dynamics of the analysed components and then the reconstruction of a more reliable template.

METHOD

The Dynamic Time Warping (DTW) [1] algorithm extends or dilates the time axes of two different sequences to minimize the distance between two corresponding samples. The alignment block procedure is based on the construction of the Warping function (WF), shown in fig. 1: to build the WF the parameters \( p \) and \( n \) are defined as follow, are needed:

\[
|f(i) - f(j)| \leq n \sqrt{m}
\]

where \( r \) represents the maximum distance between two samples to be aligned and \( p \) is the ratio between the number of diagonal steps and the number of vertical or horizontal steps. The distance measure depends on the morphological, the first and second derivatives of the signal:

\[
d_{ij} \rightarrow \sqrt{d_{ij}^1 + d_{ij}^2}
\]

where \( d_{ij}^1 \) and \( d_{ij}^2 \) are the vertical and horizontal distances between two samples, respectively.

The RRP related to each subject is decomposed in seven details and one approximation as shown in fig. 2. Filtering the signal with the functions \( G(f) \) and \( H(f) \), we obtain respectively the detail and the approximation at level \( j+1 \). Fig. 5 shows the obtained template.

RESULTS

The RRPs used for this analysis were recorded from 16 normal children of mean age 9.6 ± 0.08 yrs. The subjects underwent three different tasks: symbol presentation, letter presentation and letter recognition. The multi-scale decomposition of the signal permits to optimize the time warping procedure to the different temporal dynamics of the analyzed components and then to reconstruct a more reliable template, pointing out especially the long-latency waves as shown in fig. 6.

Such waves do not appear consistently in the grand-average because occasionally present in single subjects and with a large inter-subject variability, producing jitter and a misalignment of the RRPs (fig. 7).

CONCLUSIONS

The presented method is proposed to calculate reliable templates of RRPs and constitutes a good alternative to the classically used grand-average. The application of the Dynamic Time Warping procedure allows to overcome some pitfalls of the grand-average, and in particular the jitter always present when different subjects are considered and mainly affecting long-latency waves with high inter-subject variability. The DTW procedure has been also optimized introducing the wavelet decomposition: in fact the algorithm parameters can be optimally tuned for the different signal details.

The method has been applied in the study of reading related potentials and allowed to highlight some mechanisms involved in the reading process. The better comprehension of the underlying mechanisms, will allow a better diagnosis and classification of dyslexia in children, the planning of an individual therapy and the follow-up of the rehabilitation.

REFERENCES:

APPENDIX

The block diagram of the Block Diagram of the Warping function (WF).

Fig. 5: Diagram of the method described in the text: each RRP is decomposed through the WT, then the details of interest are aligned and the final template is reconstructed.

Fig. 6: Template superimposed to the traditional grand-average during symbol presentation task at Fz.

As shown in fig. 2, the three first details are composed principally by noise and eliminated whereas the meaningful peaks are located in a limited window, which dimension increases as the coarser scales. Therefore each signal has been windowed before the alignment, obtaining 18 samples, 9 pre-stimulus and 9 post-stimulus. The details and the last approximation are then aligned, obtaining the approximation and the details of the template, reconstructed using the Reconstruction Block in fig. 3.

The DTW is applied to the last approximation and the last four details coming from each subject, following a binary tree: the template is then obtained by a double mean procedure [3], as shown in fig. 4.

In this way, r changes with the scale considered: with the coarser scale, i.e. low-frequency waves where the number of samples decreases and the time interval between two samples increases, r (in msec) increases, while at the finer scale, i.e. high-frequency waves, r decreases. In fig. 4 an example of the alignment procedure at the fourth level is shown: the green lines connect the aligned samples of the original signals whereas the black line represents the obtained template.

This method is described in fig. 5.

Fig. 3: High-pass and low-pass filters that constitute the Basic Decomposition and Reconstruction Block. \( G(f) \) and \( H(f) \) are the detail and the approximation at the scale \( j \), whereas \( f \) and \( \gamma \) is the scale considered.

Fig. 4: Alignment of the coefficients at level D4 for the subjects shown in fig. 2, during symbol presentation task at Fz.

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