International Congress Series 1278 (2005) 429–432

www.ics-elsevier.com

Single-trial event-related potentials with wavelet denoising: method and applications

R. Quian Quiroga*

Department of Engineering. University of Leicester, UK

Abstract. We describe a method based on the wavelet transform for denoising single-trial event-related potentials (ERPs). The identification of the event-related responses in the single-trials allows the study of latency jitters and cognitive processes, such as habituation, sensitization and learning. Since the method is fast and parameter free, it could complement ERP conventional analysis. © 2004 Elsevier B.V. All rights reserved.

Keywords: Single-trials; Event-related potentials; Wavelets; Denoising; P300; Cognition

1. Introduction

Since event-related potentials (ERPs) are very low in comparison with the ongoing EEG, most of ERP research relies on the identification of peaks after averaging several trials. From the average responses, it is possible to identify evoked components, whose amplitudes, latencies and topography have been successfully correlated with several tasks, conditions and pathologies [1]. Although ensemble averaging improves the signal to noise ratio, information about the single-trial responses is lost. In particular, systematic or unsystematic trial-to-trial changes cannot be seen with the average ERP and may carry additional information related to particular behaviors, states or pathologies.

Fig. 1 shows a visual event-related potential obtained with a checkerboard pattern. This figure and the following ones are the output of a software package for denoising ERPs (EP_den) available on the Web [2]. These responses are from a left occipital electrode to 16 target stimuli of an oddball paradigm. Nontarget stimuli were color reversals of the checks. Target stimuli were also color reversal of the checks but with a small displacement. The subject had to pay attention to the appearance of target stimuli [3]. Note in the average response the presence of a first positive deflection at 100 ms (P100) followed by a negative

* Tel.: +44 116 252 2314; fax: +44 116 252 2619.
E-mail address: rqqg1@leicester.ac.uk.

doi:10.1016/j.ics.2004.11.062

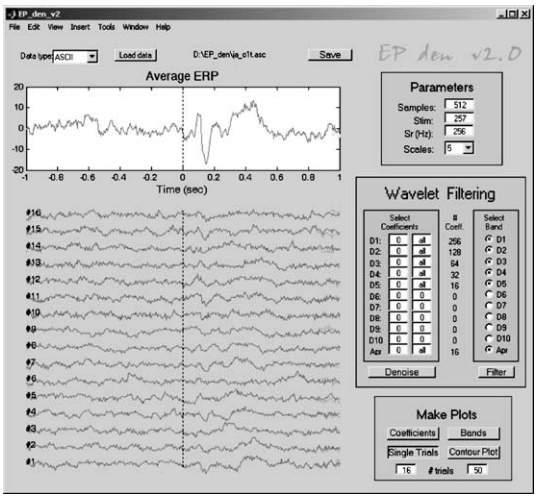

Fig. 1. Single-trials (bottom) and average (top) response to pattern visual stimulation. Note that evoked responses are clear in the average signal but are hard to be seen in the single-trials.

rebound at 200 ms (N200). At 400 ms, we observe a large and wider pear, the P300, which is usually elicited by the target stimuli. These evoked responses are clearly seen in the average signal but are hard to be identified in the single-trials. In the following, we show a method for improving the visualization of the single-trial responses based on the wavelet transform [4,5]. The wavelet transform gives a time–frequency decomposition of the signal with optimal resolution both in time and frequency. Since ERPs show multiple frequency components with different time localizations, wavelets have been very suitable for their analysis [6].

2. Denoising of single trial ERPs

Fig. 2 shows the wavelet decomposition of the average ERP of the previous figure. The signal is decomposed in six frequency bands: five 'detail' levels (D1–D5) and one final approximation (A5) [6]. D1 corresponds to the highest frequency band and A5 to the lowest. Each coefficient shows the correlation of the signal with a wavelet function at different scales and times. Note that the P100–N200 response is mainly correlated with the first poststimulus coefficient in the details D4–D5. The P300 is mainly correlated with the coefficients at about 400–500 ms in A5. This correspondence is easily identified because: (1) the coefficients appear in the same time (and frequency) range as the ERPs and (2) they are relatively larger than the rest due to phase-locking between trials (coefficients reflecting background oscillations cancel in the average). A straightforward way to avoid the fluctuations related with the ongoing EEG is by equaling to zero those coefficients that are not correlated with the ERPs. However, the choice of these coefficients should not be solely based on the average ERP and it should also consider the time ranges in which the single-trial ERPs are expected to occur (i.e., some neighbor coefficients should be included in order to allow for latency jitters). The coefficients in black are the ones used for denoising P100–N200 and P300 responses. Note that in the final reconstruction of the

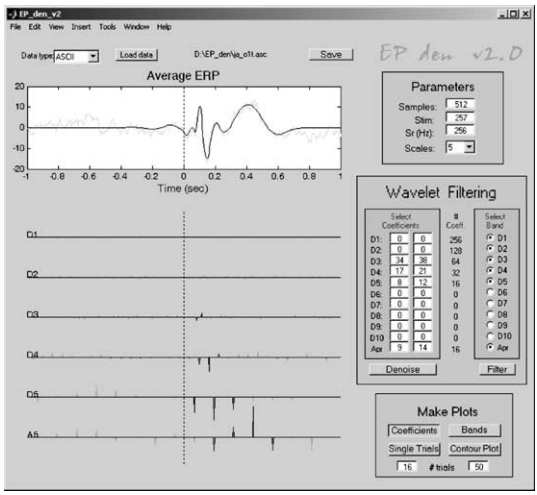

Fig. 2. Wavelet decomposition of the average ERP from the previous figure. D1–D5 and A5 are the scales (i.e., frequency bands) in which the signal is decomposed. Note that ERPs are correlated with a few wavelet coefficients (in black), which can be used to denoise the signal. On the top, the original average ERP (grey) and the denoised reconstruction of the average ERP using only these coefficients (black) is shown.

average response, background EEG oscillations are filtered. We should remark that this is usually difficult to be achieved with a Fourier filtering approach due to the different time and frequency localizations of the P100–N200 and P300 responses, and also due to the overlapping frequency components of these peaks and the ongoing EEG. In this context, the main advantage of Wavelet denoising over conventional filtering is that one can select

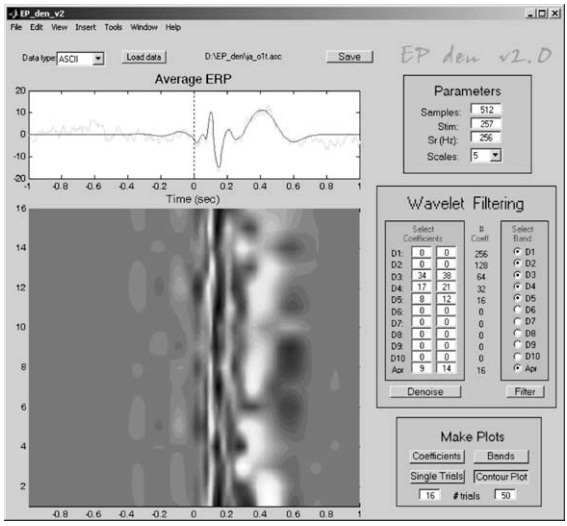

Fig. 3. Single-trial denoising of the ERP shown in the previous figure. Note that all the components are now recognized in the single-trials.

different time windows for the different scales. Once the coefficients of interest are identified from the average ERP, we can apply the same procedure to each single trial, thus filtering the contribution of background EEG activity.

Fig. 3 shows a contour plot of the 16 single trials after denoising. We observe a white pattern followed by a black one between 100 and 200 ms, corresponding to the P100–N200 peaks. The more variable and wider white pattern at about 400–600 ms corresponds to the P300. Note that with denoising, we can distinguish the P100–N200 and the P300 in most of the trials. We remark that these responses are not easily identified in the original signal due to their low amplitude and due to their similarity with the ongoing EEG (Fig. 1). In particular, it has been shown that wavelet denoising improves the visualization of the single-trial EPs (and the estimation of their amplitudes and latencies) in comparison with the original data and in comparison with previous approaches, such as Wiener filtering [5].

3. Applications of single-trial analysis

The analysis of single-trial ERPs has a wide variety of applications. By using correlations between the average ERP and the single-trial responses, it is possible to calculate selective averages including only trials with good responses [4,5]. Moreover, it is possible to eliminate effects of latency jitters by aligning trials according to the latency of the single-trial peaks [4,5]. Some of the most interesting features to study with single-trial ERPs are the changes in amplitude and latency of the peaks within an experiment. In fact, nonsystematic changes, like amplitude and latency jitters, can carry important information that is not available from the average ERPs [4,7]. Changes in the single-trial responses can be also systematic. Exponential decreases in different ERP components have been related to habituation processes both in humans and in rats [8–10]. Furthermore, the appearance of a P3-like component in the rat entorhinal cortex has been correlated to the learning of a go/no-go task [11].

References

[1] D. Regan, Human Brain Electrophysiology, Elsevier, Amsterdam, 1989.
[2] EP_den: wavelet denoising of single-trial event-related potentials. www.vis.caltech.edu/~rodri.
[3] R. Quian Quiroga, M. Schürmann, Functions and sources of event-related EEG alpha oscillations studied with the wavelet transform, Clin. Neurophysiol. 110 (1999) 643–655.
[4] R. Quian Quiroga, Obtaining single stimulus evoked potentials with wavelet denoising, Physica, D 145 (2000) 192–278.
[5] R. Quian Quiroga, H. Garcia, Single-trial event-related potentials with wavelet denoising, Clin. Neurophysiol. 114 (2003) 376–390.
[6] R. Quian Quiroga, et al., Wavelet transform in the analysis of the frequency composition of evoked potentials, Brain Res. Protoc. 8 (2001) 16–24.
[7] M.L.A. Jongsma, R. Quian Quiroga, C.M. VanRijn, Rhythmic training decreases latency-jitter of omission evoked potentials (OEPs), Neurosci. Lett. 355 (2004) 189–192.
[8] R. Quian Quiroga, E.L.J.M. van Luijtelaar, Habituation and sensitization in rat auditory evoked potentials: a single-trial analysis with wavleet denoising, Int. J. Psychophysiol. 43 (2002) 141–153.
[9] A. Sambeth, et al., Effects of stimulus repetitions on the event-related potentials of humans and rats, Int. J. Psychophysiol. 53 (2004) 197–205.
[10] A. Sambeth, et al., Enhanced re-habituation of the orienting response of the human event related potential, Neurosci. Lett. 356 (2004) 103–106.
[11] A. Talnov, et al., Enthorinal imputs to dentate gyrus are activated mainly by conditioned events with long time intervals. Hippocampus 13 (2003) 755–765.