MATCHED MEYER NEURAL WAVELETS FOR CLINICAL AND EXPERIMENTAL ANALYSIS OF AUDITORY AND VISUAL EVOKED POTENTIALS

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ABSTRACT

The wavelet transform provides a time-scale analysis that permits flexible pattern recognition, component identification, and detection of transients for time-varying neural signals such as the EEG, event-related potentials, neuromagnetic signals, and other neural signals and images. Many future applications to neural signals will benefit from choosing a mother wavelet that mimics neural waveform features. We use a recently developed algorithm to design physiologically realistic orthonormal Meyer wavelets, including 1) a wavelet that matches the prominent IV-V complex of the auditory brainstem evoked response used widely for clinical evaluation of hearing loss, and 2) a wavelet that matches ERPs containing prominent P300 components from control and alcoholic subjects. We also compare the relative naturalness of dyadic decompositions that use matched Meyer wavelets, the Haar wavelet, and Daubechies D4 wavelet. Designer neural wavelets have broad potential to customize and improve neurometric imaging and clinical neurodiagnosis of sensory and cognitive dysfunction.

1 INTRODUCTION

The wavelet transform (WT) has attractive properties for analyzing and efficiently storing neuroelectric and neuromagnetic signals and images, including variable measurement resolution matched to the scale of waveform features, computational simplicity and speed, excellent compression capability, and perfect reversibility for precise and specialized waveform filter design [1].

The core element in a wavelet analysis is the mother wavelet, a localized time-domain function satisfying certain admissibility conditions [2]. In the WT of a time-varying neural waveform $s(t)$, the mother wavelet $g(t)$ is scaled by a and translated in time by b to form a wavelet family, and the inner products of this family with the waveform are taken as in (1).

If orthonormal, the wavelet may be used in a multiresolution analysis (MRA), where an *n*- sample waveform is decomposed into an efficient set of *n* orthonormal wavelet bases at discrete time scales, $a = 2^j$, and translations, $b = 2^j k$, for *j*,*k* integers, using a simple pyramidal filter scheme of computational complexity that is merely O(*n*) [3].

$$W(a,b) = \frac{1}{\sqrt{a}} \int_{t=-\infty}^{\infty} s(t) g^{*}\left(\frac{t-b}{a}\right) dt \quad (1)$$

Zeroing or manipulating some of the wavelet coefficients in (1) prior to waveform reconstruction allows precise filtering of neural waveforms for experimental and diagnostic purposes. Discarding zero, near zero, or application-irrelevant coefficients in MRAs of neural signals can yield impressive lossy compression ratios [4].

Besides the appeal of the WT as a mathematical tool for neural waveform decomposition, there is now evidence that the brain accomplishes aspects of sensory-perceptual construction by performing its own WT on sensorineural signals [9]. Wavelet representations, then, may play a basic role in the representational functions of the central nervous system. Hence, wavelets may be physiologically natural basis functions that are optimally suited to study biologically important neural functions and to satisfy the ubiquitous need of neuroscientists and clinicians to decompose neural signals into meaningful components.

The WT has been applied successfully to neural waveform analysis problems such as detection of epileptic activity [5], denoising of single-trial event-related potentials (ERP) [6], prediction of human signal detection performance from ERPs [7], and identification of scale-specific visual evoked response correlates of retinal degeneration [8]. Future applications will benefit by using wavelets optimally designed to analyze neural signals. In this paper we illustrate a method of designing Meyer wavelets matched to neural waveform features.

1.1 Rationale for Matched Neural Wavelets

Many neural signals are of interest to the neuroscience and neuroclinical communities, each exhibiting characteristic time-dependent spectral and waveshape properties. These include electroencephalographic (EEG) and magneto-encephalographic (MEG) signals, epileptic spikes, state-related EEG spindles, sensory evoked potentials, intra-cranial unit recordings, and so on.

Any wavelet, regardless of its shape, can decompose such neural signals into energy distributions that localize waveform information in time and scale (frequency),