Compensation for Speed-of-Processing Effects in EEG-Data Analysis

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Abstract. We study averaging schemes that are specifically adapted to the analysis of electroencephalographic data for the purpose of interpreting temporal information from single trials. We find that a natural assumption about processing speed in the subjects yields a complex but nevertheless robust algorithm for the analysis of electrophysiological data.

1 Introduction

In electroencephalographic (EEG) data noise levels of -25dB are not uncommon [1], for electromyography (EMG) or functional magnetic resonance imaging (fMRI) the situation is similar. The arising problem of the recovery of relevant information from such data has been dealt with extensively [2,3,4]. It seems reasonable to exploit intrinsic structures in the data, i.e. to identify patterns in the data that reoccur under specific conditions, e.g. at the onset of a stimulus or in relation with other events in the course of the experiment.

A straight-forward solution consists in averaging single-trial *event related potentials* (ERPs) in order to obtain an averaged ERP (AERP) that is expected to be comparable across different experimental setups [3]. The reliability of the AERP allows for the identification of characteristic features of the time course of the signal such as the latency and amplitude of major minima and maxima, which may be used iteratively to further improve the process of averaging. We will discuss several algorithms that are not only theoretically justified, but have proven useful also in an experimental project [5,6]. Systematic changes in the AERP components between different experimental conditions are consistent with the hypothesis that ERP components do reflect stages of information processing in the brain. In this interpretation, the idealized noisefree ERP represents the signal of interest and variability across trials is merely noise.

The data that gave rise to this studies has been obtained in a series of EEG experiments. A subject was engaged in a priming task (cf. [5] for more details on the priming effect) and supposed to respond to a stimulus. The stimulus configuration presumably triggered various modes of internal processing in the subject, cf. Fig. 1. Some of the behavioral effects turned out to be fragile and require a large number of trials to

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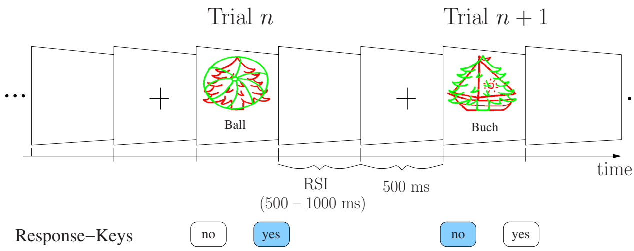

Fig. 1. Time course of a trial of the psychophysical experiment. Subjects are asked to identify the green (light gray) stimulus in presence of a red (dark gray) distractor. If the target matches the written word then the correct response is “yes”. Stimulus presentations are interleaved with response-to-stimulus intervals (RSI) and fixation phases. Depending on which stimuli from the previous trial are repeated, reaction time can be increased or decreased.

become significant. The underlying information processing mechanisms are studied by simultaneous EEG recordings which we assumed to obey the following conditions.

1. The EEG signal contains the relevant components of the neural activity.
2. Task-specific activations form a significant fraction of the EEG signal.
3. The brain solves similar tasks in a similar way.

The *signal* can now be defined as a minimal variance curve within the data set obtained for many repetitions of the same task. The axioms imply that variations due to external conditions should be excluded and that the external conditions and even the state of the subject should be kept as constant as possible for all trials. Yet, data mining techniques reveal that for comparable data only a fraction of 60% of the pooled epochs contribute to the AERP waveform while the other 40% just increase the variance [7].

Thus, it cannot be decided unambiguously whether the variability of the ERPs is caused by the stochastic nature of the underlying neural dynamics or by the application of different strategies to the task. A plot of the single-trial ERPs and the AERP, see Fig. 3, points already to a basic problem: Simple averaging will deteriorate in particular late components of the ERP (such as the *Late Positive Complex*) which which make the interpretation of these components difficult.

2 Models for Event-Related Potentials

The signal-to-noise ratio (SNR) of EEG data is typically enhanced by combining data epochs that are supposed to contain a certain signal component as a pointwise average

$$\langle s_i(t)\rangle_i = \frac{1}{N}\sum\nolimits_{i=1}^{N} s_i(t) \qquad i = 1,\ldots,N. \tag{1}$$

Here $s_i(t)$ is the measurement of the ith trial, $1,\ldots,n$, at time t. The *signal-plus-noise* (SPN) model [8] or *fixed-latency* model [9] underlying this average assumes that (i) signal and noise add linearly, (ii) the signal is identical in all trials, and (iii) noise is a zero-mean random process drawn independently for each trial.