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A New Statistical Model of EEG Noise Spectra for Real-time, Low-γ-band SSVEP Brain-Computer Interfaces

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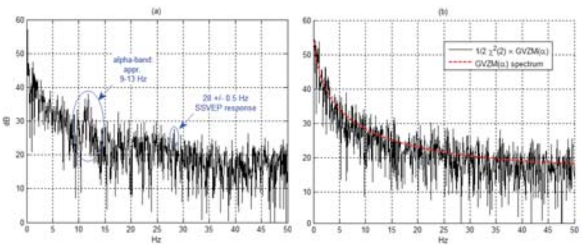
Introduction: A major impediment to practical real-time γ-band (≥ 30Hz) SSVEP BCIs is the high level of spectral noise which dramatically increases the error rates of frequency detectors/estimators (Fig. 1a). The standard "1/*f*-type" spectral model [1] of EEG noise is both theoretically unsatisfactory and too ill-defined for hypothesis tests. Based on our new theory of *quantum ion channel kinetics* [2], we model EEG noise spectra as random processes of the form $S_{\mathrm{EEG}}(f) = S_{\mathrm{GVZM}}(f)\cdot\Xi(f)$, where $\Xi(f)$ are independent $\chi^2(2)/2$ random variables at each frequency f and $S_{\mathrm{GVZM}}(f)$ is the *generalized van der Ziel-McWhorter* deterministic function whose inverse Fourier transform is $R_{\mathrm{GVZM}}(t) = P_0\int_{\tau_1}^{\tau_2}(1/\tau^{\alpha})e^{-t/\tau}\,d\tau + P_1\delta(t)$ for tunable parameters $\alpha, \tau_1, \tau_2, P_0, P_1$ (Fig. 1b). We show such noise models have superior statistical characteristics for BCI and other neuroengineering applications.



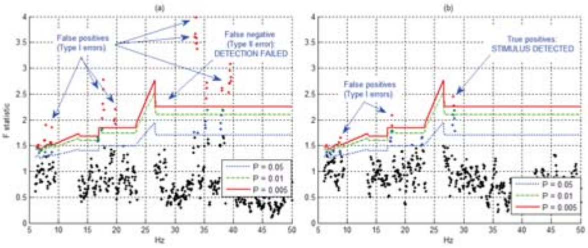


Figure 1. *(a) Raw single-trial EEG spectrum from 28Hz SSVEP BCI experiment showing a response peak which is nearly indistinguishable from background noise. (b) Synthetic GVZM* $\cdot\chi^2(2)/2$ *noise spectrum optimally- fitted to the data of (a).*

Figure 2. *(a) Critical levels for SSVEP detection/estimation using standard smoothed periodogram algorithm [4] and the data of Fig.1. (b) Detection/estimation using optimally-fitted GVZM* $\cdot\chi^2(2)/2$ *statistics.*

Material, Methods and Results: The model was tested on a 15-second, 28Hz SSVEP trial (Fig. 1a) from a publically-available BCI dataset [3]. Biosemi electrodes A14-A16, A21-A23, A25, A27-A29 were averaged to form a virtual visual electrode. Blink artifacts were estimated by linear regression onto the three frontal electrodes. A popular *F*-test SSVEP detection algorithm [4] was compared to the same algorithm with its pre-stimulus estimator replaced by our optimally-fitted GVZM $\cdot\chi^2(2)/2$ statistic. Each spectral value (excluding mid-α- and low-β-bands) was classified with respect to its *F*-test critical value calculated from the null hypothesis of no stimulus at that frequency. The results are shown in Fig. 2.

Discussion: The standard algorithm [4] failed to detect the 28Hz response spike in the noise background and also produced numerous false positives (Fig. 2a). On the other hand, our GVZM-based algorithm not only accurately detected the 28Hz response with $P < .005$, it also produced far fewer false positives (Fig. 2b).

Significance: This work proves that it is feasible to detect/estimate low-γ-band SSVEP spikes in real-time despite their poor signal-to-noise characteristics by using neurologically-appropriate statistics for EEG background noise. Such noise models will be essential for the development of future practical real-time SSVEP BCIs in the mid-γ-band.

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