429.5

Differentially Variable Component Analysis (dVCA): A Single-Trial Analysis Method for Sensory Responses and Ongoing Oscillations

429.5

AS Shah[1,2], KH Knuth[3], P Lakatos[2], CM Chen[2], CE Schroeder[1,2]

[1]Department of Neuroscience, Albert Einstein College of Medicine, Bronx, NY 10461

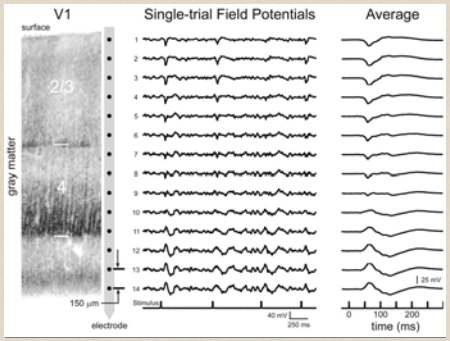
[2]Cognitive Neuroscience & Schizophrenia Program, Nathan Kline Institute, Orangeburg, NY 10962

[3]Computational Sciences Division, NASA Ames Research Center, Moffett Field, CA 94035

Studying single-trials

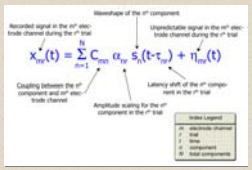
Single-trial, event-related potentials (ERPs) capture both evoked and induced activity. Typically, these potentials are averaged across presentations of the stimulus to reduce noise while enhancing the evoked responses. However, averaging masks trial-to-trial variability in the evoked response, and the dynamics of this variability may be related to higher-order cognitive functions such as perception. We previously introduced the differentially Variable Component Analysis (dVCA) technique to characterize this variability and to evaluate single-trial, evoked responses. In addition, subtracting the evoked activity from the single-trial ERP permits the study of induced activity. Here, we will demonstrate the application of dVCA to data collected from primary visual cortex of a macaque monkey. We will highlight some of the major capabilities of this technique, but we will not provide an in-depth analysis of these data.

Data collection



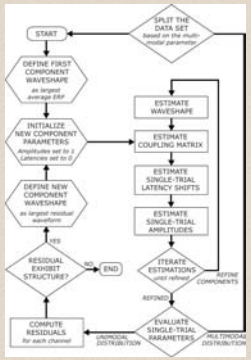
Data were collected from primary visual area V1 of an awake macaque monkey by acutely inserting a linear-array electrode into the brain. Field potential activity was sampled continuously at 2000 Hz, while the subject was presented with randomly interspersed standard and target visual stimuli at an average rate of 2/sec. The standard visual stimulus was of a 10-µs, red-light flash, and the target varied slightly in intensity. The monkey released a lever after each presentation of the target stimulus to earn a drop of juice.

The Model



The model underlying dVCA states that a single-trial ERP consists of evoked activity plus some unpredictable signal. The evoked portion (first term on the right-hand side of the equation) refers to activity that is relatively time- and phase-locked to stimulus presentation. On the other hand, the unpredictable signal consists of induced non-phase locked activity and noise.

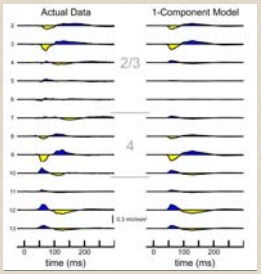
The Algorithm

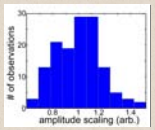


Bayes' theorm is utilized to express the posterior probability of the model above. From this *maximum a priori* solutions are computed for each parameter of the model. A fixed-point algorithm is used to estimate the most probable parameter set for our model.

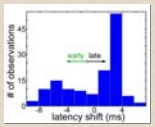
Applying dVCA

dVCA was applied to 137 single-trial ERPs recorded in response to the standard stimulus. A 1-component model was estimated for these data, and its current source density (CSD) profile is illustrated. Not surprisingly, the 1-component model captures much of the activity shown in the average CSD profile of the actual data.



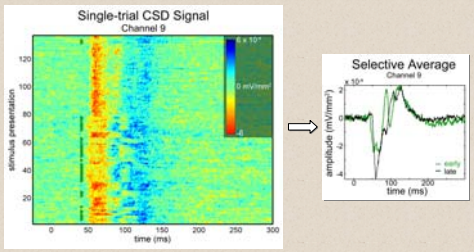


The histogram of amplitude scales illustrates that the variability in this component's amplitude is quite small (standard deviation - $\sigma_{amplitude}$ = 0.173).



The histogram of the latency shifts shows a bimodal distribution with peaks at -5.63 and +3.13 ms. Based on the guidelines of the algorithm, we split the data set in two and generated an "early" and "late" subset.

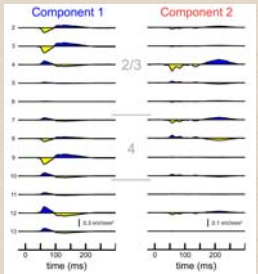
Verifying the dVCA Results

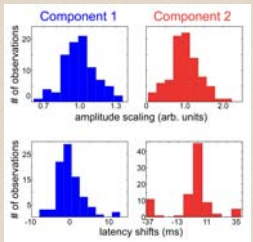


Visual inspection of the actual single-trial CSD signals illustrates that several neural responses diverge from baseline prior to the majority, and these trials coincide with those predicted as "early" by the dVCA estimates (green ticks in left figure). Selectively averaging data according to the early and late designations confirms that the onset latency of the CSD signal in the early subset precedes that in the late subset (right figure).

Examining Evoked Activity

dVCA was applied to the 88 trials comprising late subset. Two components were estimated as per the algorithm. The onset latency of the first component was 38 ms and that of the second component was 44 ms.





The amplitude scale and latency shift histograms show that component 2 is more variable than component 1.

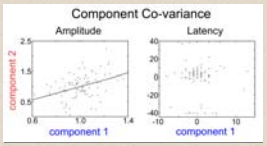
$\sigma_{\alpha 1}$ = 0.136

$\sigma_{\alpha 2}$ = 0.392

$\sigma_{\tau 1}$ = 3.28 ms

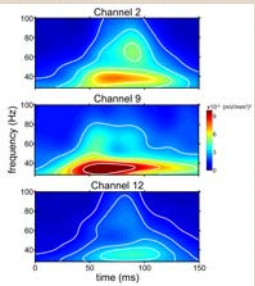
$\sigma_{\tau 2}$ = 18.11 ms

Examining Evoked Activity Continued



There is a significant positive correlation between the amplitude of component 1 and 2 ($r = 0.38$, $p < 0.001$), but there is no relation between the latency shift estimates even if the extreme points of component 2 are excluded.

Studying Ongoing Activity



The unpredictable signals in the late subset were calculated by subtracting the 2-component model from the actual data in each trial. Single-trial, time-frequency (TF) maps were calculated and averaged across trials to generate the plots shown on the left.

Layer 2/3 (Ch. 2) - γ-band activity (34-50 Hz) peaks at 71.5 ms and 38 Hz, while the very high frequency (VHF) activity (52-76 Hz) peaks at 89.5 ms and 65 Hz.

Layer 4 (Ch. 9) - γ-band activity peaks at 65 ms and 35 Hz

Lower layers (Ch. 12) - γ-band activity peaks at 80 ms and 36 Hz

Summary

The dVCA technique permits researchers to study single-trial ERPs, which capture both evoked and induced activity. By characterizing the evoked activity and its variability, one can study how single-trial ERPs vary with system wide variables such as attention and arousal or with behavioral measures such as reaction time. Moreover, this information may be used to evaluate how different components co-vary in the same brain area or across brain regions. Finally, dVCA allows researchers to evaluate ongoing activity, which may contain induced oscillations. These capabilities of dVCA suggest that this technique may further our understanding of neural mechanisms underlying perception.

Acknowledgements

We thank Tammy McGinnis, Noelle O'Connell, Aimee Mills, Dr. Wilson Truccolo, Dr. Mingzhou Ding, and Dr. Steven Bressler. The work was supported by T32M07288, MH60358, NASA IDU/IS/CICT Program, and NASA Aerospace Technology Enterprise.

Please visit 430.19 for more details on the dVCA technique, and please see 485.19 (this afternoon) for a study of ongoing activity using the dVCA technique.