Estimating sensory delays to primate M1: a comparison of peri-stimulus time histograms and coherence phase-frequency regression

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Introduction

Coherence analysis is widely used to investigate oscillatory phenomena in the nervous system.

Coherence is a measure of correlation in the frequency domain between two signals.

Coherence phase indicates the average phase difference between the signals at a given frequency.

For a system with a fixed delay, phase (θ) is linearly related to frequency (f) with a slope related to the delay (τ):

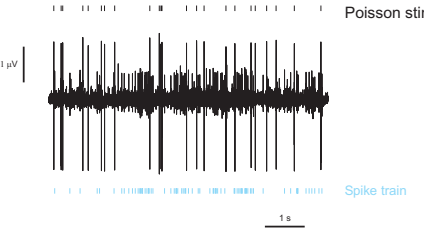
$$\theta(f) = 2\pi\tau f$$

It is commonly assumed that coherence phase analysis will yield similar delay estimates to response latencies, measured using time-domain methods such as the peri-stimulus time histogram (PSTH).

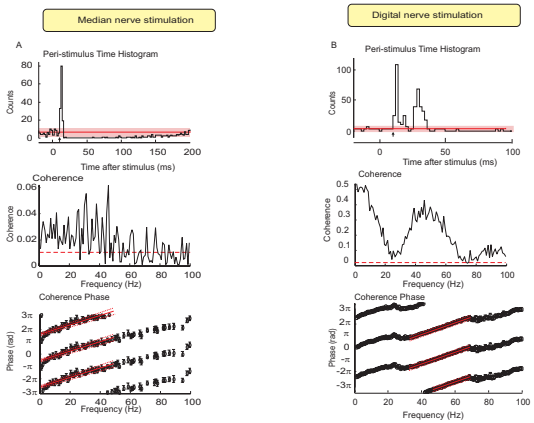
In this poster, we examine this assumption.

Methods

- Microelectrode penetrations into primary motor cortex of a macaque monkey, sedated using ketamine/medetomidine. Single unit activity isolated.
- Electrical stimulation of median nerve at the arm (biphasic stimuli, 0.2ms per pulse, intensity at motor threshold), or digital nerve of index finger (10mA)
- Stimuli delivered as Poisson stimulus trains[1], mean rate 10Hz.

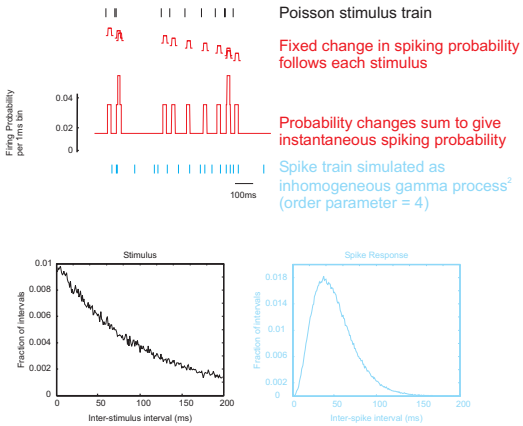


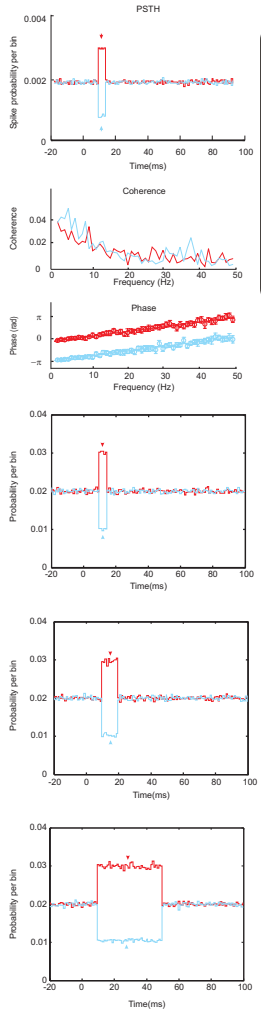
Experimental Results



Delays estimated from coherence phase-frequency slopes are substantially higher than from PSTH onset latency: in the examples above 18 vs 10 ms for the median nerve stimulation, and 17 vs 10 ms for the digital nerve stimulation.
We investigated this further using simple computer simulations.

Simulation Methods





Example simulation results where cell responded with a brief facilitation (red) or suppression (blue) of its firing (onset latency 9.5ms, duration 10ms)

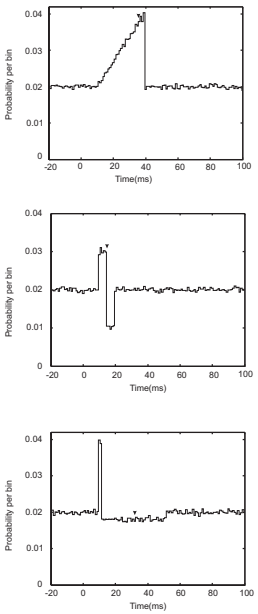
Coherence was greater at low frequencies, reflecting the low-pass filtering consequences of the response duration.

Phases differed by π radians between facilitation and suppression. Regression slopes implied a delay of 14.5ms (arrowheads on PSTH).

Results from simulations with the same response onset latency, but with increasing response duration.

The latency estimated from the coherence phase-freqeuncy regression (arrowheads) was always close to the middle of the response.

Examples of delay estimated from coherence phase for more complex response profiles. Each plot shows the PSTH, and the coherence delay estimate (arrowhead).



For a more complex response profile, the coherence delay estimate was close to the centroid (centre of mass) of the response.

When the response included both a facilitation and suppression, coherence delay estimate was close to the centroid of the *absolute* response profile (i.e. Ignoring its sign).

Physiological responses often include an initial brief facilitation, followed by a long lasting, but weak, suppression (e.g. the experimentally recorded example cell A). In a simulation mimicking this, the coherence delay estimate was substantially larger than the onset latency, as it was affected by the suppression.

Conclusion

Using coherence phase-frequency relationships to estimate delay measures the average delay of the whole response, not just the onset latency. This must be remembered when comparing coherence delays with measurements in the literature, which are usually based on the earliest response to a stimulus.

In some circumstances, coherence delay estimates may be more functionally relevant than those based on onset latency.

References

1. Miller S, Clark J, Eyre JA, Kelly S, Lim E, McClelland VM, Mc Donough S & Metcalfe AV. (2001). Comparison of spinal myotatic reflexes in human adults investigated with cross-correlation and signal averaging methods. *Brain Res* **899**, 47-65.
2. Baker SN & Gerstein GL. (2000). Improvements to the sensitivity of gravitational clustering for multiple neuron recordings. *Neural Comput* **12**, 2597-2620.