THE STATISTICS OF MEMBRANE POTENTIALS USING A BILINEAR MODEL

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ABSTRACT

Proportional (multiplicative) noise (PN) is a ubiquitous phenomenon in the nervous system. Representations of quantitative (prothetic) sensory stimuli are perturbed by noise with a standard deviation proportional to the mean level (Weber's law). Similar relationships exist in motor behaviour, where the noise on force is also proportional to the mean (Fitt's law). There has been no satisfactory explanation for this phenomenon, and it may be a fundamental and inevitable property of the transmission of information within the nervous system, or between the nervous system and the external world.

Previously we have examined the possibility that PN may reflect the ensemble statistics of neuronal membrane potentials or muscle forces, resulting from the influx of spike trains that are renewal processes (RP) (where inter-spike-intervals (ISIs) are identical independent random variables). It was shown that PN was not a natural feature of spike rate of RPs. However, if the counting interval was itself stochastic, PN could emerge. This was then extrapolated to generate PN for the linear shot-noise problem where the impulse response function was itself stochastic; reflecting hypothesized random fluctuations in the dynamical coefficients of membrane potential, $V(t)$. It was shown that a simple 1st order system with random coefficient, *a*, could account for observed PN $V(t) + aV(t) = u(t)$, where $u(t)$ is the RP input spike train [1].

We now consider a more realistic non-linear model in which passive membrane potential is described by a bilinear 1st order differential equation $V(t) + bV(t) = v(t)u(t)$, where b is a fixed deterministic leakage constant. This simple single compartment model reflects the multiplicative effect between the membrane potential, $V(t)$ and the change in conductance induced by incoming action potentials, $u(t)$. Clearly, if $u(t)$ is stochastic, it effectively introduces variability in the 1st order coefficient as previously modelled. Therefore, we explore the possibility that PN could arise from the stochastic nature of the membrane potential when $u(t)$ is a stochastic process given by an incoming spike train with renewal properties.

We also discuss how the statistics of membrane potentials and spike trains may differ, and raise the dilemma of whether we attribute representations to membrane potentials or spike trains.

Keywords: Proportional noise, internal representation, non-linear dynamics

References

[1] Harris CM (2002) Temporal uncertainty in reading the neural code (proportional noise). *Biosystems* **67**: 85-94.