Supplementary material for *Firing-rate models capture essential response dynamics of LGN relay cells*

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Model implementation differences

The following sections summarize any differences between the original model implementations and our implementations in NEST.

Casti model

According to Casti et al (2008), the afterhyperpolarization is modelled as alpha-function conductances that are added for each spike (see Section 2.1.1). The source code obtained from the authors, however, only keeps track of the conductance resulting from the most recent spike. The NEST implementation adds the conductances as described in the model equations. This difference causes noticeable differences in the output only at high input rates. As an option, the NEST implementation allows the user to behave like the original.

Also, Casti et al use a second-order Runge-Kutta integrator and linear interpolation to determine the spike times. In the NEST model, a fourth-order integrator and linear interpolation is used. This difference seems to have negligible effects.

Carandini model

The main difficulties in implementing the Carandini model in NEST, was related to the noise signal $n(t)$. It had to be generated and filtered in advance, resulting in a memory-intensive model. And the noise signal was not described in the paper, but the source code detailing the signal parameters and the filtering process was obtained from the authors. However, we were not able to run the original simulator and therefore unable to directly compare the results of the two implementations.

Tables and figures

Optimal parameter sets for all neurons from Casti et al (2008) and Carandini et al (2007) are listed in 1 and 2 respectively.

In the main text, we presented a number of figures illustrating the results for four Casti neurons, while the results from the Carandini model were summarized in a single figure. Here, stationary response (Figure 1), response to sinusoidal stimuli (Figure 2), and rate-model prediction (Figure 3) figures are included for four representative Carandini neurons.

Figures illustrating the response to sinusoidal stimuli and rate-model prediction at a different working point are included for both neuron models (Figures 4–7).

References

Carandini M, Horton JC, Sincich LC (2007) Thalamic filtering of retinal spike trains by postsynaptic summation. J Vis 7(14):20.1–2011

Casti A, Hayot F, Xiao Y, Kaplan E (2008) A simple model of retina-LGN transmission. J Comput Neurosci 24(2):235–252

Table 1: Optimal parameter sets for all neurons modeled by Casti et al (2008). Neurons were stimulated with small spots, except for those with an asterisk suffix, which were obtained with a larger than optimal stimulus. After Casti et al (2008, Table 2).

Neuron	τ (ms)	τ_A (ms)	$\bar{g}_E$	$\bar{g}_A$
1	17.8	0.47	0.16	0.42
1*	11.7	0.60	0.11	0.56
2	17.1	0.40	0.16	0.48
2*	17.3	0.50	0.13	0.54
3	12.6	0.25	0.08	0.54
3*	13.6	0.14	0.07	0.49
4	19.5	0.37	0.09	0.55
5	22.0	0.41	0.19	0.60
6	16.3	1.00	0.08	0.60
6*	11.8	1.00	0.07	0.57
7	14.4	1.07	0.08	0.28
8	7.2	0.26	0.07	0.44
9	12.4	0.60	0.08	0.52
10	15.3	0.65	0.10	0.60

Table 2: Optimal parameter set for all neurons modeled by Carandini et al. After Carandini et al (2007, Table 1).

Neuron	τ_{EPSP} (ms)	V_{EPSP}	τ_{reset} (ms)	V_{reset}	V_{noise}
120L15-1	7.4	0.77	6.3	4.39	0.15
121R11-1	14.2	0.86	20.9	2.37	0.35
121R13-4	8.4	0.62	9.5	6.64	0.30
121R14-4	17.2	0.57	33.4	0.78	0.00
121R15-5	5.8	0.93	7.5	1.34	0.10
121R7-1	5.8	0.97	6.3	2.54	0.05
122R4-2	6.3	0.91	29.9	0.85	0.20
122R4-3	5.6	0.73	12.3	1.04	0.20
122R4-5	6.0	0.56	12.0	0.82	0.25

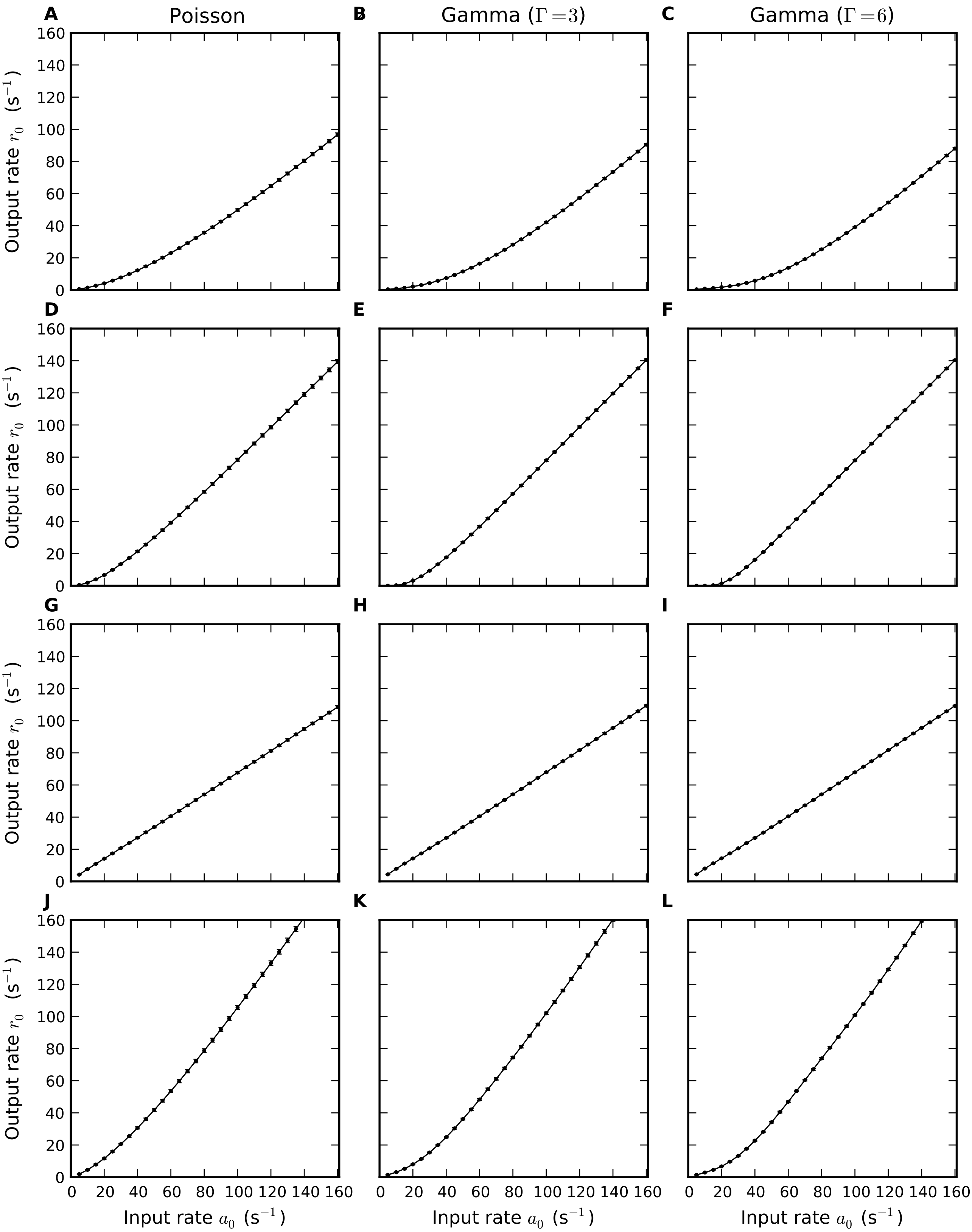

Figure 1: Stationary response for selected Carandini neurons. Symbols illustrate mean output rates r_0 across trials. Error bars denote one standard deviation in either direction. Each row contain results from one neuron configuration, from top to bottom: 122R4-5, 121R14-4, 121R11-1 and 121R15-5. Columns represent different input regularities, from left to right: Poisson ($\Gamma = 1$), gamma ($\Gamma = 3$) and gamma ($\Gamma = 6$).

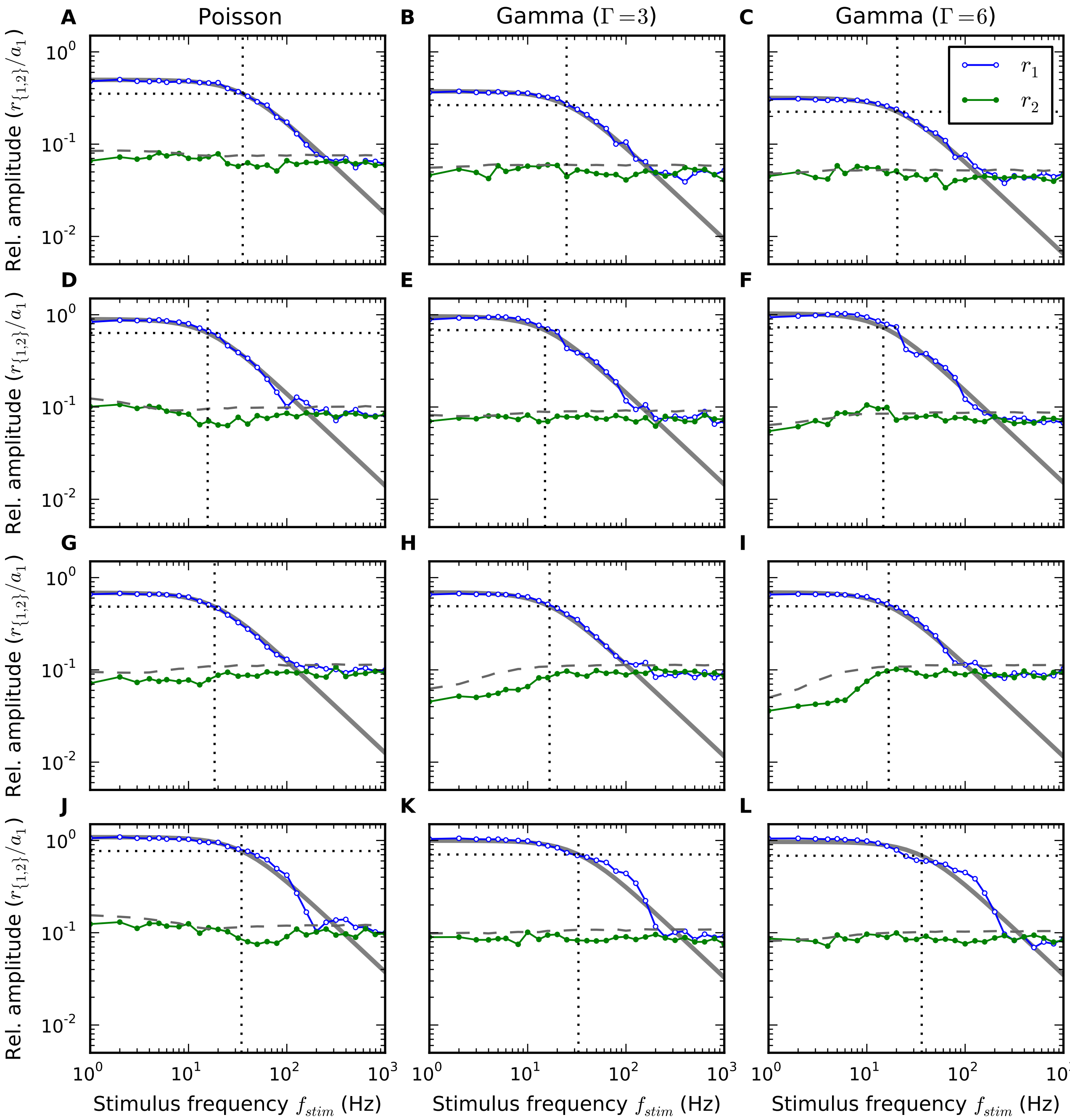

Figure 2: Low-pass characteristic of the response to sinusoidal stimuli ($a_1 > 0$) for representative Carandini neurons. The figure illustrates how a first-order low-pass filter with cutoff frequency f_c, low-frequency gain γ, and delay d fits the response of the Carandini model to time varying input. Symbols represent measured responses $r_n(f_{\text{stim}})/a_1$ for principal (blue) and second (green) harmonics ($n \in \{1, 2\}$). Gray curves show fitted first-order low-pass filters. Dotted vertical lines mark fitted cutoff frequencies f_c. Dashed horizontal lines represent noise level $z = 2$. Stimulus parameters: $a_0 = 40\,s^{-1}, a_1 = 10\,s^{-1}$. Same panel arrangement as in Figure 1.

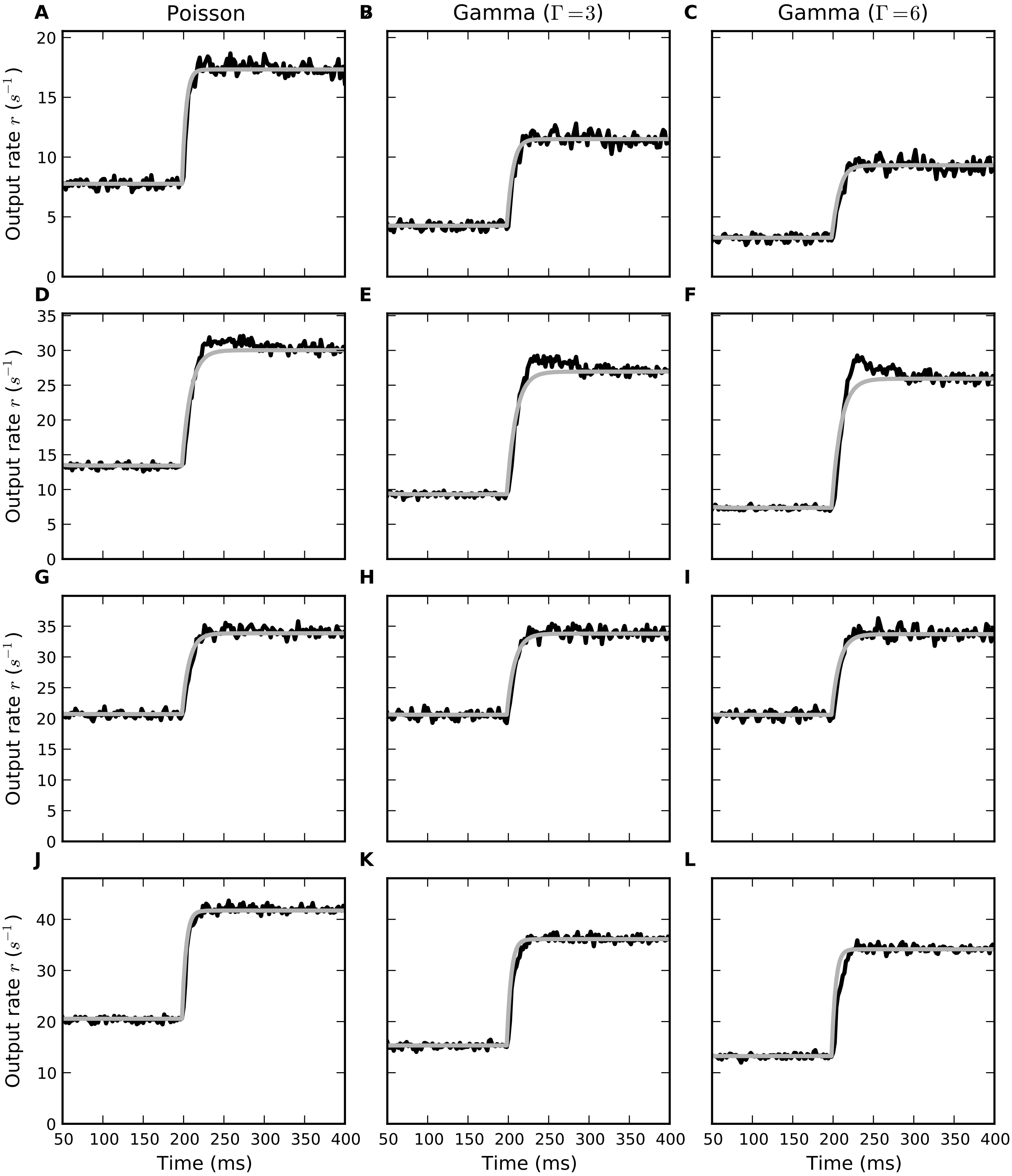

Figure 3: Population-averaged step responses for selected Carandini neurons. Firing rate $r(t)$ in response to an instantaneous increase in the input firing rate $a(t)$ at time $t = 100$ ms from 30 to 50 s^{-1}. Same panel arrangement as in Figure 1.

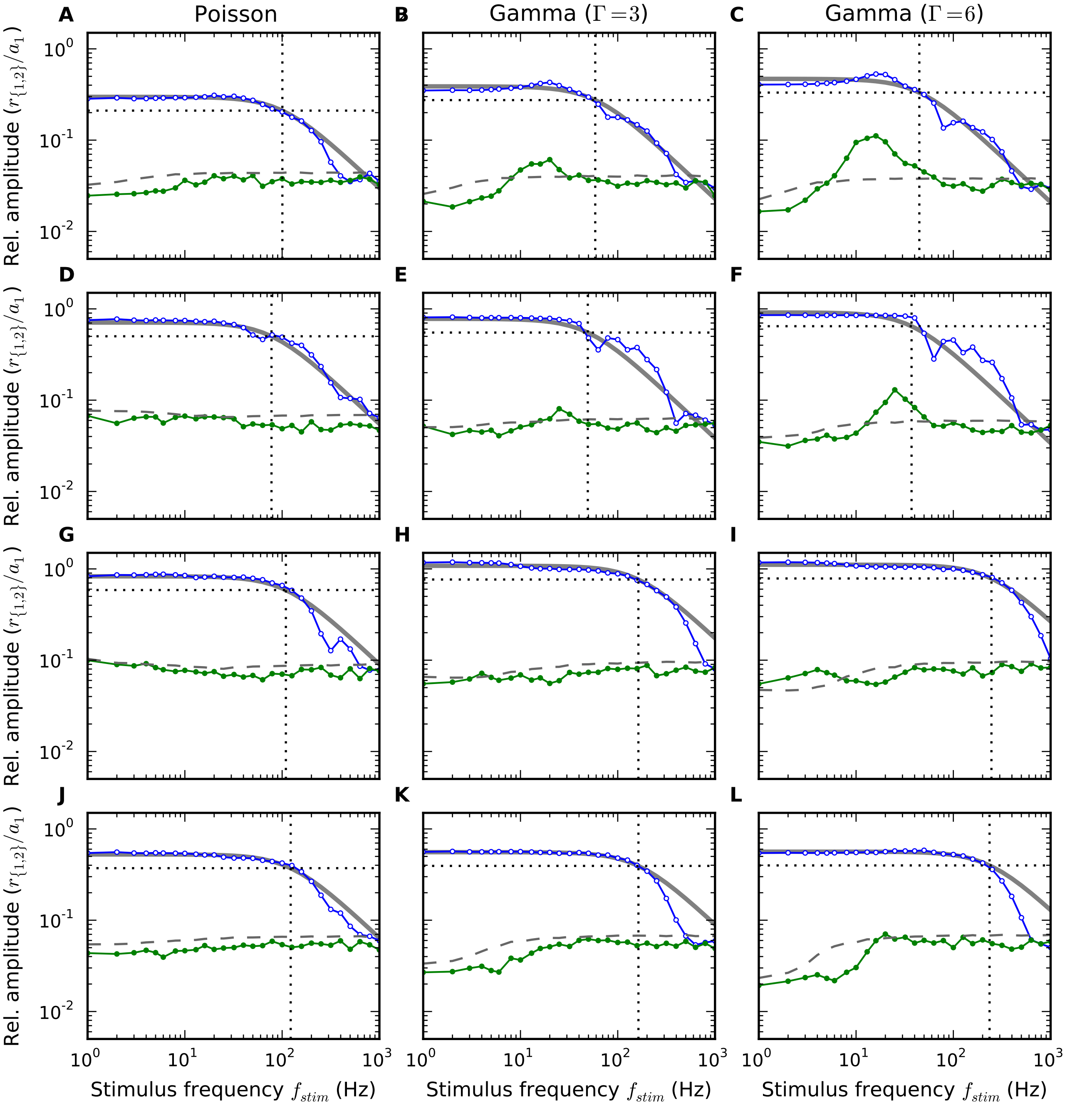

Figure 4: Low-pass characteristic of the response to sinusoidal stimuli ($a_1 > 0$) for representative Casti neurons (high input rate). Stimulus parameters: $a_0 = 80\,s^{-1}, a_1 = 20\,s^{-1}$. Same panel arrangement as in Figure 1.

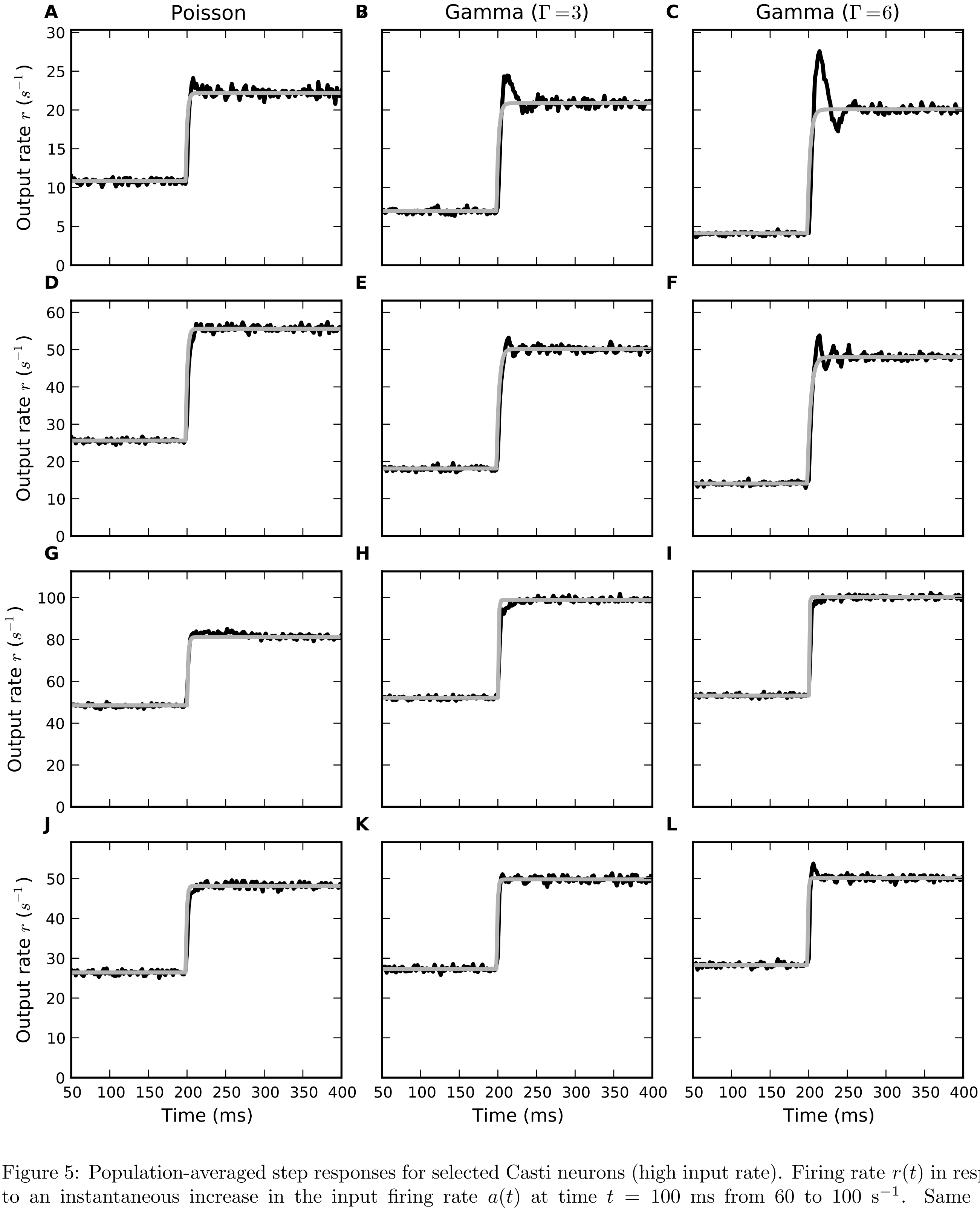

Figure 5: Population-averaged step responses for selected Casti neurons (high input rate). Firing rate $r(t)$ in response to an instantaneous increase in the input firing rate $a(t)$ at time $t = 100$ ms from 60 to 100 s^{-1}. Same panel arrangement as in Figure 1.

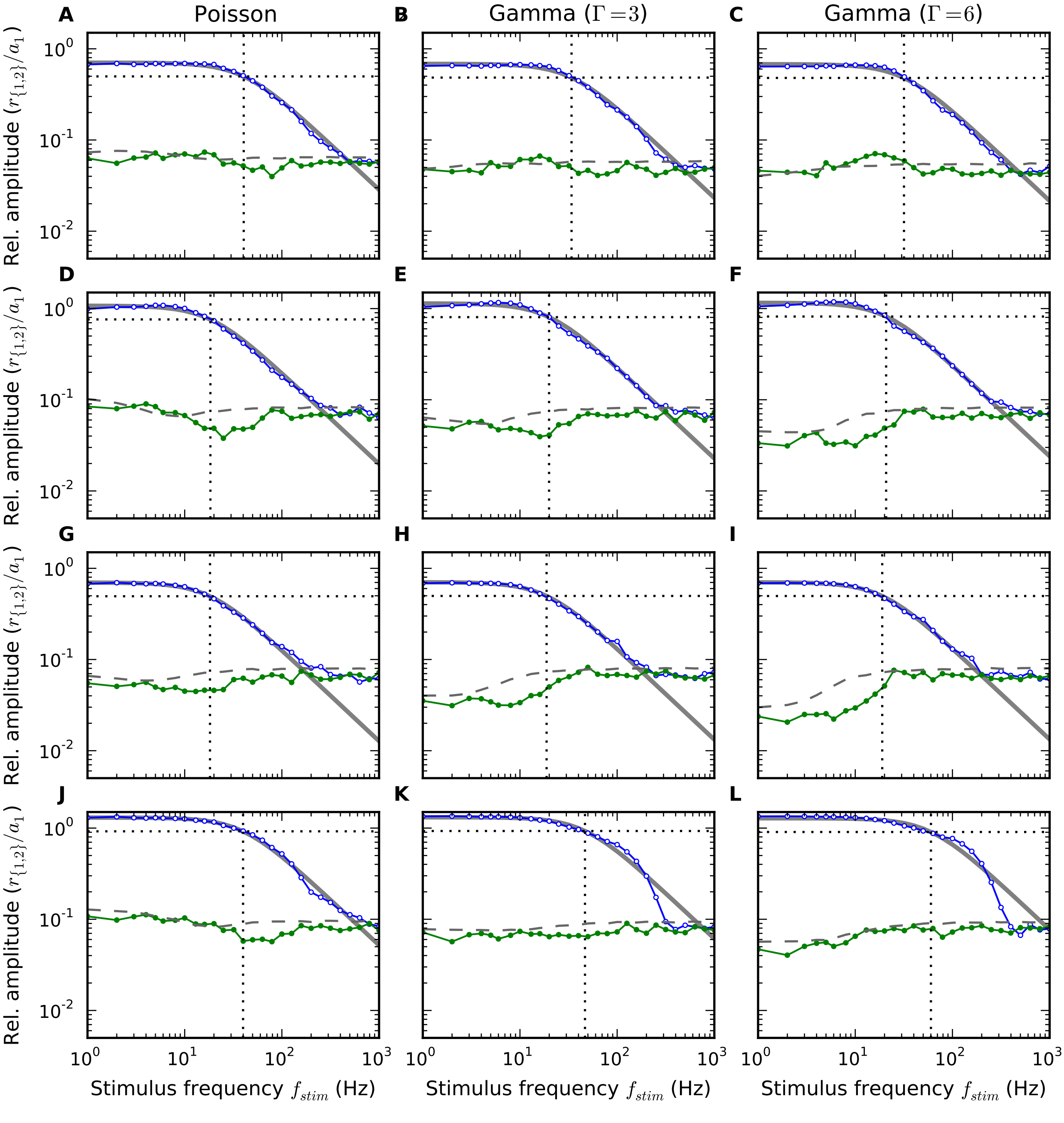

Figure 6: Low-pass characteristic of the response to sinusoidal stimuli ($a_1 > 0$) for representative Carandini neurons (high input rate). Stimulus parameters: $a_0 = 80\,s^{-1}, a_1 = 20\,s^{-1}$. Same panel arrangement as in Figure 1.

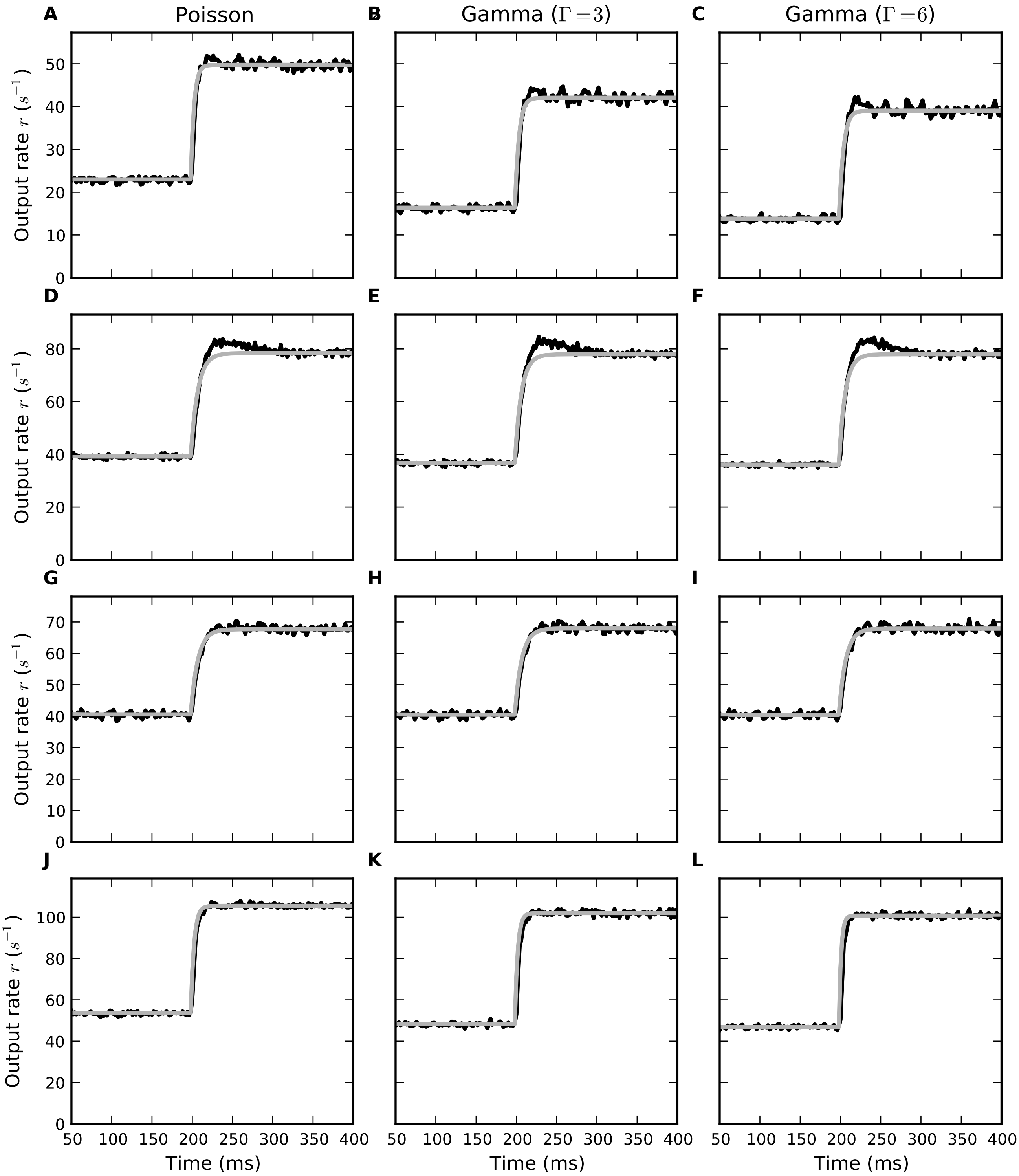

Figure 7: Population-averaged step responses for selected Carandini neurons (high input rate). Firing rate $r(t)$ in response to an instantaneous increase in the input firing rate $a(t)$ at time $t = 100$ ms from 60 to 100 s^{-1}. Same panel arrangement as in Figure 1.