Burst Encoding in the Metathoracic Ganglion of Grasshoppers

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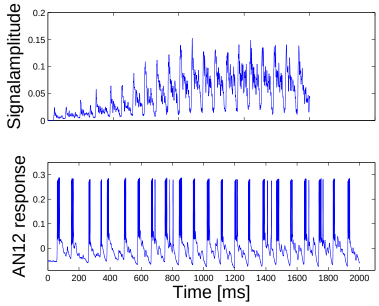
1 Introduction

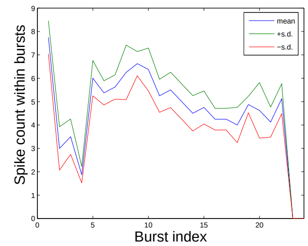
Grasshoppers of the group Acrididae rely on acoustic communication via species-specific songs (1). These songs consist of alternating syllables and pauses. In auditory information processing, the grasshopper system has to master several tasks, the most important are localization and song identification/ discrimination. Information about acoustic stimuli is transmitted via receptor neurons into the metathoracic ganglion, where information is processed in interneurons. From there, ascending neurons (ANs) forward the information into the head ganglion which controls the motor output. The number of ascending neurons is relatively small (ca. 15 at each side) and, hence, they constitute a bottleneck for information transmission. Previous studies have shown that interneurones process both location and song patterns, whereas ANs either encode location or song pattern (2). Here, we analyze the role of one specific neuron - the so-called AN12 - in transmitting behaviourally relevant information.

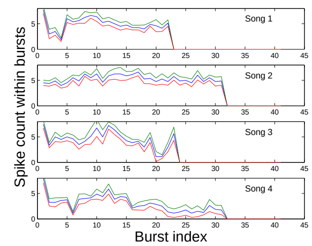
2 Naturally occurring song and AN12 response



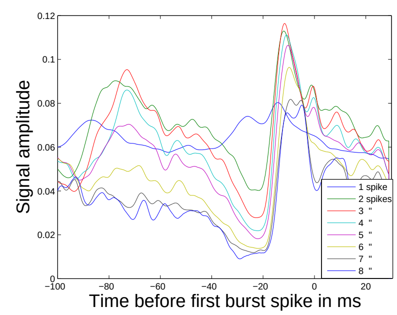
3 Burst position code

The AN12 marks the onset of each song syllable with a burst of spikes. The spike count is specific for the preceding syllable. Hence, different songs have different spike count patterns. For further analysis, we evaluated only the last part of songs where the absolute amplitude level is in a steady state.

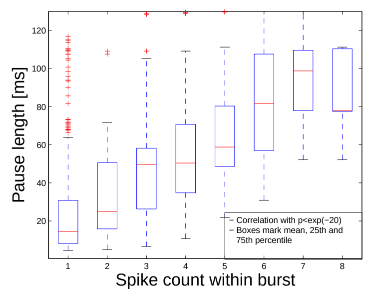




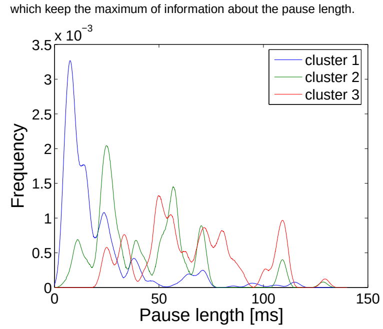
4 Burst triggered average



5 Pause length encoded



The spike count carries up to 1.5 bits about the pause length (1 axonal recording, 3 dendritic recordings reveal a mutual information between 0.5 and 1 bit). Hence, the spike count can roughly discriminate between three different distributions of pause lengths. We used the agglomerative information bottleneck algorithm (3) to find three clusters of spike count distributions which keep the maximum of information about the pause length.

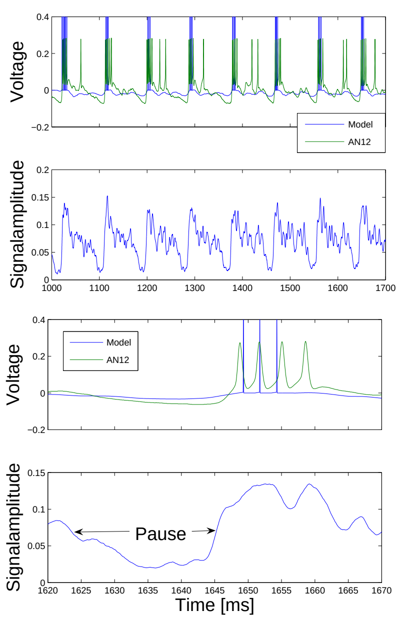


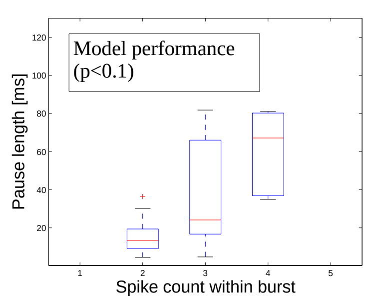
6 Modeling the system

We checked different computational models. The quality of our models was evaluated counting the coincident spikes and normalizing them with respect to the overall number of spikes in original data and model. Measuring the variance in the original data, the reference quality measure was 0.84.

- Our first hypothesis was a leaky Integrate & Fire model with three parameters, i.e., the spiking threshold, the reset value and the time constant of the decay. Model quality: 0.35. This model was not specific enough in marking the syllable onset.
- In a second step, we took the time derivative of the signal before feeding it into the Integrate and Fire model (Differentiate & Integrate & Fire). Onset marking improved but overall model quality remained the same. Hybrid models, i.e. giving a mixture of amplitude and differentiated amplitude as input, did not advance the model quality either.
- Third, we additionally smoothed the signal with a sliding window. Using a sliding window width (4th parameter) of 12 ms, we obtained a model quality of 0.79 - most features of the original spike train were successfully reproduced.
- Note that Differentiation and Smoothing is commutative. Also, smoothing with a sliding window is integration over a certain range, thus, reversing the differentiation, but leaving one positive and one negative term of the original amplitude. Hence, it is possible to interpret the model as follows: The AN12 gets its input via one excitatory input channel and one inhibitory input channel with relative latency of 12 ms. This interpretation asks for an additional (5th) parameter: the relative input strength of the excitatory and inhibitory channel. Surprisingly, this relative input strength is very close to 1 and the model quality is improved only slightly (0.80).
- The Integrate & Fire model is linear and cannot reproduce neural behaviour very well. We tried the more realistic Quadratic Integrate & Fire model, also optimizing for all paramters mentioned above. However, model quality was limited to 0.65.

7 Comparing model with real data





8 Conclusion

The AN12 reliable encodes the pause length in natural occuring mating songs. From behavioural studies one knows that the pause length is the single most important factor determining the overall song quality. The encoding of the pause lengths of 2-3 syllables may be sufficient to transmit behavioural relevant information about the overall mating song quality. Our modeling results imply that preprocessing smooths and differentiates the original signal. A possible implementation is suggested by interpreting the model as an excitatory and an inhibitory channel with different latencies. Surprisingly, the model consists of a very simple integrating mechanism (Integrate & Fire) not reflecting the non-linearities of real neurons. This suggests that computation on network scale may filter out non-linearities and follows straight-forward principles.

References:

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2. Stumpner, A, Ronacher, B (1991) Auditory interneurones in the metathoracic ganglion of the grasshopper Chorthippus biguttulus. I. Morphological and physiological characterization. *J. Exp. Biol.* 158, 391-410
3. Slonim, N, Tishby, N (1999) Agglomerative Information Bottleneck. *Proceedings of NIPS-99*

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