Paired Spiking Is an Ubiquitous Response Property in Network Activity

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Abstract

In paired spiking (PS), a neuron generates two action potentials within a time window of 2-5 milliseconds followed by a refractory period up to several hundred milliseconds. Regardless of the neuroscientific context, whether in cultured neural networks or in intact brain architectures, in spontaneous activity or in response to stimuli, PS has been found in any type of spike trains. Recent evidence shows that PS forms spatiotemporal patterns and participates in establishing functional and effective connectivity in networks of cultured neurons of different types [1]. Another prominent example is PS participation in neural communication at the retinogeniculate synapse *in vivo* [2]. However, little is known on the richness and robustness of its function and its coding mechanisms at both single cell and network level. Here, we show that PS activity forms robust activity patterns with most frequently occurring inter-paired spike intervals (mfoIPSIs) of 1 sec. Its shape within the recorded spike trains of retinal ganglion cells (RGCs) is furthermore preserved between local sites and at network level under different stimuli conditions. Furthermore, PS carries information on the stimulus that was applied to the receptive field of the recorded RGCs. However, the information density differs for different cell types. This suggests that PS may change its contribution to information transmission relative to the type of the recorded cell according to its morphological, physiological and structure-function classification.

1 Backround

Ursey *et al.* explained how PS enhancement may shape the neural response *in vivo* [2]. Recent findings show that a key role within the concept of sparse coding efficiency is played by PS activity. Both *in vivo* and *in vitro,* PS preserves information from one stage to the next in both stimulated and spontaneous activity [1], [3]. Presumably, it represents an ubiquitous response property of different types of neurons in different species. Here, we analyzed extracellularly recorded activity from different types of RGCs, using different stimuli, and discuss PS involvement in shaping retinal spike trains and its role in information processing. Additionally, in simulations [4], we quantify the PS-related information being transmitted to a modeled postsynaptic neuron.

2 Methods

We analyzed extracellularly recorded stimulated neural activity from different isolated retinal slices from mice and rabbits using multielectrode arrays (Multichannelsystems). For mouse retinal whole mounts, we repeatedly applied light pulses of 1.5 s duration by LEDs emitting at different wavelengths [5]. The second stimulus consisted in moving grating bars at different directions over the rabbit retinal slices, which allowed us to calculate the direction selectivity index (DSi) [4]. In this case, we used an Integrate and Fire model to simulate the postsynaptic counterpart for each recorded RGC [4]. For both stimuli, we extracted the PS activity within the recorded spike trains. We then quantified the information content that PS carried about the stimulus with respect to that of the overall spike activity [1]. However, we only considered the relative percentage by dividing the mutual information (MI) carried by PS-related activity by that carried by the entire spike train [1].

3 Results

Recently it has been shown that PS develops activity patterns in spontaneous neural activity of cultured neural networks [1]. Our results indicated that spatiotemporal PS patterns are robust in all trials. We found that the number of mfoIPSIs from individually recorded RGCs could reach 250 while at network level numbers up to 600 were counted. The highest number of PS for a trial at individual recording sites was ≤1500 while the number of PS at network level was ≤2500 (Fig. 1 c and d). The inter-paired-spike interval (IPSI) distribution at both single site and network level shows that the mfoIPSI was steady at 1 sec. for all trials (Fig. 1 a and b). The information processing function had different shapes for different cell types. Thus, the mean amount of information about the stimulus that was carried by PS related activity was varying from 5% up to 60% (Fig. 2b). However, at net-

work level, it was fluctuating less between 20% and 30% (Fig. 2c).

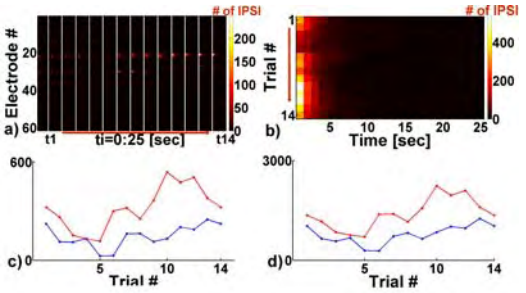

Fig. 1. IPSI distribution at individual sites a) and network level b). c) Number of repetitions of mfoIPSI at network level (red) and at individual sites (blue). d) Number of PS at network level (red) and highest number of PS at individual sites (blue).

Fig.2a depicts the evolution of PS-related information for each trial at individual channels showing a rather robust shape for each channel at different trials.

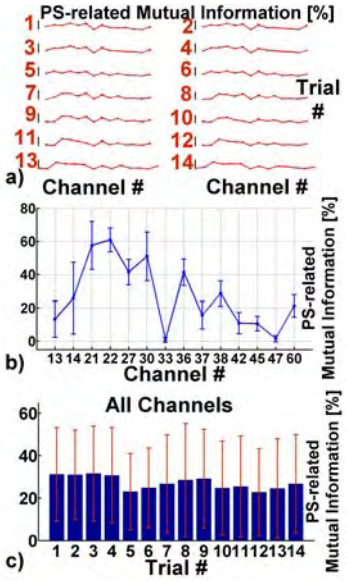

Fig. 2. a) PS-related information carried by each channel (X axis) as depicted in b), for each trial (Y axis). Vertical bars represent 100%. Mean PS-related information carried by each channel for all trials (b) and for each trial by all channels (c).

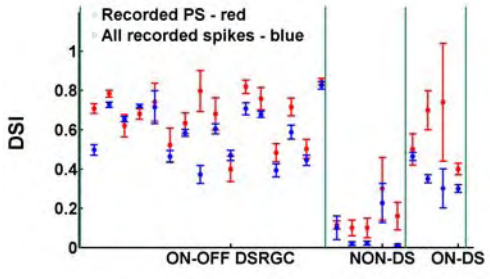

Fig. 3. DSi for PS (red) and for the entire spiking activity (blue) for different RGCs separated by green vertical bars.

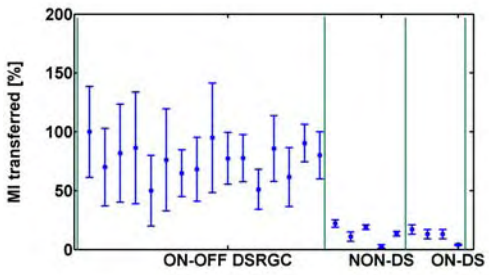

Fig. 4. Percentage of PS-related mutual information (MI) transferred to the modelled postsynaptic counterpart for each RGC. Lower values are for non directional cells (NON-DS) and for ON-DSRGCs (ON-DS).

Applying a drifting grating bar stimulus we found that PS-related information that had been transferred to the modeled counterpart neuron in the lateral geniculate nucleus (LGN) was between 50% and 98% for ON-OFF DSRGCs and much below 50% for other types of RGCs (Fig. 4). However, the DSi was always higher for PS than for the entire recorded spiking activity for all cells (Fig. 3).

4 Conclusion

Our findings show that PS shapes the neural activity in recorded RGCs under stimulus condition. While PS forms robust spatiotemporal patterns for all types of cells, its shape varies with cell type. Interestingly, the information carried by PS varied with cell type as well. For instance, for ON-OFF DSRCs, PS activity carries most of the information regarding the stimulus direction. This finding is sustained by morphological and functional explanations. For example, ON-OFF DSRGCs perform one-to-one connectivity with their LGN counterparts. Thus, PS from a single cell becomes crucial, while in ON-DSRGCs multiple cells send convergent inputs toward their counterparts in the accessory optic system (AOS). Presumably, the information is enriched as a consequence of heterosynaptic mechanisms. The latter mechanism holds true at higher brain areas and suggests that PS changes its shape from mono- to polysynaptic contributions.

References

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