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Discriminability measures and time–frequency features: An application to vibrissal tactile discrimination



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HIGHLIGHTS

- We proposed four discriminability measures to quantify differences of experimental conditions.
- The methods are based on information theory, percentage overlap and divergence between distributions.
- The methods were evaluated on experimental protocols related to vibrissal tactile discrimination.
- The methods indicate the time intervals where sweep conditions have higher probability of being discriminated one from other.
- The methods here proposed can be adapted to many other features of biological responses.

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ABSTRACT

Background: Often, the first problem that the neuroscientist must face is to determine if a specific stimulus set applied to biological system produces specific, precise and well differentiated responses.

New method: In the present study we have proposed four discriminability measures to evaluate the feasibility of differentiating experimental conditions: information measures based on information theory, percentage overlap based on Linacre method, Bhattacharyya distance and univariate standard distance. All discriminability measures were evaluated on experimental protocols related to vibrissal tactile discrimination.

Results: Time–frequency features were extracted from afferent discharges and then, pairwise comparisons were realized by using the proposed discriminability measures. Our results reveal the existence of time–frequency patterns which allows differentiating of sweep conditions from multifiber recordings. **Comparison with existing methods:** Currently, statistical methods used to justify significant differences in experimental conditions have rigorous criteria that must be met for correct validation of results. Discriminability measures proposed here are robust and can be adjusted to different experimental conditions (time series, repeated measures, specific variables and other).

Conclusions: Discriminability measures allowed determining the time intervals where two sweep situations have the highest probability to be differentiated from each other. High discriminability percentages were observed into protraction phase, although to a lesser degree, it was also observed in retraction phase. It was demonstrated that sensibility of discriminability measures are different. This revealing a greater ability to highlight percentage changes of pairwise comparisons. Finally, the methods here proposed can be adapted to other features of biological responses.

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1. Introduction

Understanding how neurons represent, process, and manipulate information is one of the main goals of neuroscience (Victor, 2006). Therefore, the nervous system has to interpret what is going on in the real world through the neuronal responses. In short, this means identifying a particular stimulus (or extracting

the value of a stimulus parameter) by using the responses of one or more neurons (Dayan and Abbott, 2005). The first problem that the neuroscientist must face is to determine if a specific stimulus set applied to biological system produces specific, precise and well differentiated responses. Often this first exploration is performed through a time–frequency analysis (Victor, 2006).

Time–frequency (or spectrotemporal) analysis is a general exploratory method that is particularly suitable for neural data, both spiking and continuous (Mittra and Pesaran, 1999). This analysis allows identifying meaningful statistical structure in spike trains. Its frequent use is due to that neural signal, especially those influenced by external stimuli, are nonstationary (i.e. its statistical properties change along time). Therefore, neural signal is segmented into periods that are sufficiently brief so that within each one, the signals can be assumed stationary. Then, standard spectral analysis applied to each segment can then reveal how the frequency characteristics of a signal evolve over time. Thus, time–frequency analysis provides specific information which can be related to neural encoding of sensory information. For this, a specific stimulus set applied to biological system should produce time–frequency features well differentiated.

The discriminability of neural responses evoked by different stimuli is one of the main indicators of existence of some neural encoding. Discriminability measures have been derived from information theory (Shannon, 1948) and signal-detection theory (Green and Swets, 1974). Information theory has been applied to quantify the amount of information conveyed by neuronal responses (Borst and Theunissen, 1999; Haag and Borst, 1997; Koch et al., 2004; Passaglia and Troy, 2004). Measures of the discriminability of neuronal responses have been applied to estimate the relevant time scale of neuronal coding (Kretzberg et al., 2001; Machens et al., 2001) or to quantify the response reliability (Grewe et al., 2003; Chichilnisky and Rieke, 2005). Both types of reliability measures, i.e. the theoretical information and the signal-detection ones, shed light on the accuracy with which a sensory system encodes stimuli (Grewe et al., 2007).

In this paper, we have proposed four discriminability measures, one of which is based on information theory. The second proposed method is based on estimates of percentage overlap between normal distributions proposed by Linacre (1996). The third and fourth measures are Bhattacharyya and Univariate standard distances which are measures of divergence between two distributions (Bhattacharyya, 1943; Flury and Riedwyl, 1986). All discriminability measures were applied to texture discrimination problem in the rat vibrissal system (Albarracín et al., 2006).

It is well known that rats acquire sensory information by actively moving their vibrissae, and a neural code is manifested at different levels of the sensory system (Arabzadeh et al., 2006; Diamond et al., 2008; Farfán et al., 2013). Particularly, Wolfe et al. (2008) found that when a vibrissa sweep over a rough surface, it experiences changes in its trajectory characterized by irregular and skipping motions (known as slip-stick events) and thus producing a pattern of slip-stick events which would be related to surface features like the size of grains and the distance between them. Farfán et al. (2013) showed that it is possible to identify electrophysiological events evoked by mechanical slip-tick events by exploring the afferent activity recordings, and that these would allow discrimination of rough surfaces at peripheral level.

Here, we analyzed the afferent discharge from a deep vibrissal nerve when the vibrissa sweeps materials (wood, metal, acrylic, sandpaper) having different textures. Just like Albarracín et al. (2006), here we also consider the change of slip-resistance of vibrissa over surfaces as a way to improve the tactile information acquisition. Time–frequency features from afferent recordings were obtained for each experimental condition (sweep over different surfaces). Then, pairwise comparisons were realized by

using the proposed discriminability measures. We demonstrated that experimental sweep conditions can be discriminated with time–frequency features and discriminability measures.

2. Materials and methods

2.1. Procedures

Five Wistar adult rats (300–350 g) were used in our experiments. They were anesthetized with urethane (1.5 g/kg) and their temperature was maintained at 37° by a servo-controlled heating pad. Surgery consisted of exposing the infraorbital nerve as well as the two branches of the facial nerve (buccal and upper marginal mandibular) on the right side. The motor branches were dissected and transected proximally to avoid possible motor influences on the sensorial pathway. The stimulation electrodes were placed on their distal stumps to produce the contraction of the mystacial muscles. The deep vibrissal nerve innervating a vibrissal follicle (Gamma vibrissa) was identified with a high magnification dissecting microscope. The dissected nerve was also transected proximally and this action allowed eliminating discharges arriving from higher level of the sensorial pathway. To make sure that the nerve transection did not affect the functionality of the vibrissal nerve during our recording time, we have tested the reduction in the nerve afferent activity throughout the time (data not shown). We concluded that the activity starts decreasing approximately over 1 h after the nerve transection, so we never exceeded this space of time in our experiments. We used a bipolar electrode (insulated silver wire, 0.2 mm diameter) to record the multifiber afferent discharge of the vibrissal nerve selected. The recording electrodes as well as the nerves were immersed in a mineral oil bath during all recording.

All these procedures were carry out in accordance with the recommendations of the Guide for the Care and Use of Laboratory Animals (National Research Council, NRC).

2.2. Recording of the vibrissa electrical activity

In this study we have recorded the multifiber activity of the Gamma vibrissal nerve while the vibrissa was sweeping surfaces of different textures. The experimental protocol used in this paper has been previously described in detail by Albarracín et al. (2006) and Farfán et al. (2011, 2013). The procedures are briefly described below.

Vibrissa movements were induced by electrical stimulation of facial motor nerve (VII). Square-wave pulses (30 μ s, 7V supramaximal,¹ 5 Hz) simulated vibrissal whisking at its natural frequency (a diagram of experimental set up is shown in Fig. 1B).

Nerve activity was recorded and digitized at 20 kHz (sampling rate, Fs) during a 100 ms window following onset of each cycle of whisker movement with a Digidata 1322A (Axon Instruments). Fifty whisker movement cycles were obtained for each surface, and an additional 50 cycles were recorded while whisker moved unobstructed in air (control).

Four slip-resistance levels were presented for each surface by mounting the surface at different distances from the whisker base. A minimal slip-resistance level was presented by placing the surface at a maximal distance from the whisker base so that the tip just barely contacted the surface throughout the entire movement cycle (slip-resistance 1). Increased slip-resistance levels were presented by moving the surface 3, 6 or 9 mm closer to the whisker base (slip-resistance 2, 3 and 4, respectively) (Albarracín et al., 2006).

¹ A supramaximal stimulation should simultaneously depolarise all of nerve fibres within the nerve. It is 20–50% above a stimulation that causes maximal response.

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