Intersegmental Synchronization of Spontaneous Cord Dorsum Potentials as a Clinical Parameter to Evaluate Changes in Neuronal Connectivity Produced by Peripheral Nerve and Spinal Cord Damage*

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Abstract. We describe here an automatic selection method to retrieve spontaneous cord dorsum potentials from the spinal cord in the anesthetized cat. Previous studies have indicated that some of these potentials appear synchronized in several spinal segments and are generated by the activation of specific sets of dorsal horn neurons. Since their synchronization is affected in a characteristic manner by acute peripheral nerve and spinal lesions, as well as during capsaicin-induced skin inflammation, they can be used to describe the patterns of functional interconnectivity between specific sets of dorsal horn neurons, which makes them of potential clinical interest.

1 Introduction

We have recently examined the functional organization of the neuronal ensembles involved in the generation of spontaneous cord dorsum potentials (CDPs) in the lumbo-sacral spinal cord of the anaesthetized cat. Although spontaneous CDPs with different shapes and amplitudes appear synchronously along several spinal segments, we have focused our attention to the analysis of the spontaneous negative CDPs (nCDPs) and of the spontaneous negative-positive CDPs (npCDPs), because of their functional relations with the pathways that control information transmitted by cutaneous afferents [1]. The synchronization between these potentials appears to be the expression of non-random patterns of functional interconnections between segmentally distributed sets of dorsal horn neurons [2] which are modified by spinal cord and

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peripheral nerve lesions [1] and by capsaicin-induced skin inflammation [3]. So far, we have retrieved the nCDPs and npCDPs using a fixed template complemented with visual selection [1]. This has taken an enormous amount of time. Here we present the basis of an automatic classification method devised to facilitate the analysis of larger amounts of raw data required for a more detailed analysis of the changes in the interconnections between these sets of dorsal horn neurons produced by peripheral nerve lesions and skin inflammation.

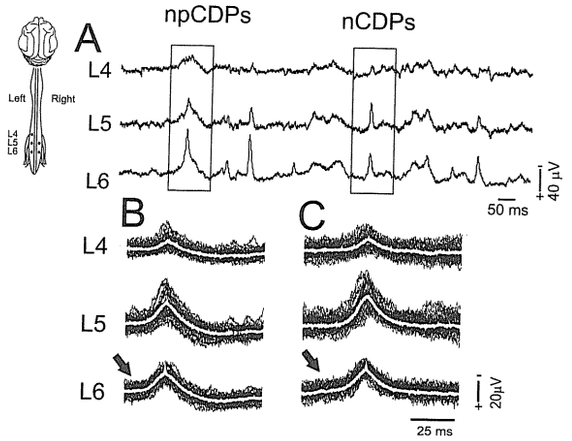

Fig. 1 A, spontaneous synchronized cord dorsum potentials simultaneously recorded from 3 spinal segments (L4-L6). Boxes show npCDPs and nCDPs. B and C, superposed npCDPs and nCDPs retrieved from another experiment selected by means of predetermined templates using as reference the potentials recorded from the L6 segment (arrows). White traces show means. Modified from [1].

2 Methods

Spontaneous CDPs were recorded by means of an array of several ball electrodes placed over the surface of the exposed lumbosacral cord in the anesthetized cat (see Figure 1). These potentials were recorded using separate amplifiers with a wide band from 0.3 to 10KH. They were digitized with a sampling rate of 10 KHz and stored for subsequent processing.

2.1 Detection of CDPs in Each Spinal Segment

In order to detect the synchronized CDPs using the method proposed here, we first processed the raw recordings from different spinal segments each of them separately to detect CDPs lasting 50-300 ms with amplitudes above 5

μV (see figure 1). To this end, a sliding window of a fixed length was defined and used to go through the whole sequence of potentials recorded from a given segment. In order to reduce the noise in the signal, a high frequency filter was applied to each time window and its maximum was computed. If this maximum was around the center of the window a CDP was marked, if not, the window was moved so that maximum was in the center of the window and the procedure was repeated until all the signal was processed. Candidates to CDP whose peaks were below a predetermined threshold, were not considered. This method recovered 1,266 candidates as interesting CDPs from a recording of 400 seconds of raw recording. However, 1,184 of them were not actually relevant.

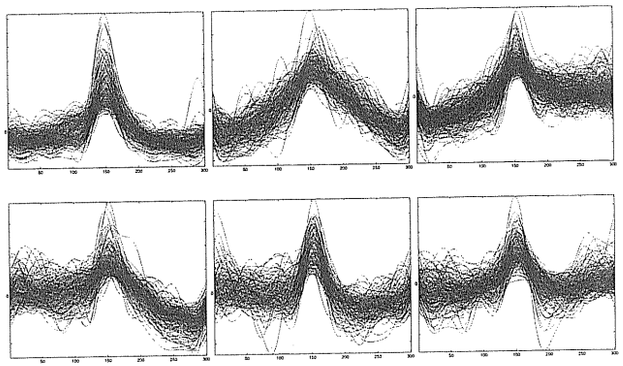

Fig. 2 Patterns found in spinal segment L6 by applying non-supervised clustering algorithm *k-means* (k=6) to the set of CDPs extracted from raw recording. Representation of patterns is made superimposing smothered CDPs assigned by *k-means* to each pattern. As shape of patterns is more important than actual voltages, voltage of CDPs have been normalized. Each window lasts 180 ms.

2.2 Detection of Basic CDP Patterns

In this step we sorted in an unsupervised way CDPs detected in the previous step. The implementation of this step included (1) noise reduction in CDPs by applying a Fourier filter for higher frequencies, (2) normalization of the resulting CDPs, and finally (3) a clustering process using the well known *k-means* method [4]. This process was done for each spinal segment. Basic CDP patterns found using this procedure, for the data on one spinal segment, are presented in figure 2. These patterns have been validated by experts founding that the two leftmost patterns shown in figure 2 are specially interesting because they covered a significant part of signals with a clear biological interpretation, in particular the purely negative and negative-positive

CDPs starting from a flat baseline (for details see [1]). The upper one covered 37% of data marked by the expert as interesting CDPs from the set of CDPs extracted from raw recordings. The lower one covered another 18% of interesting CDPs. Both patterns recovered 55% of interesting CDPs, allowing to keep 362 CDPs of which 45 were actually interesting and discarding 904 CDPs of which only 37 were actually interesting. These results are encouraging for a non-supervised method. We expect to obtain better results using supervised methods. However, the final inspection of results by the experts is necessary in order to remove potentials that could be artifacts or artificial patterns created by the *k-means* method. Time required to execute this step and the previous one is on the order of minutes. The results of this step are a dictionary of basic patterns, and a method that automatically classifies a CDP as one entry in this dictionary. The next two steps of the methodology we propose are currently being implemented.

2.3 Detection of Concurrence of Simple Patterns

After finding a set of basic CDP patterns, we propose to study the correlation between them in different spinal segments. We will automatically count, for *each possible combination of basic patterns and spinal segments*, the number of occurrences in the recorded registry. Then we will translate this counting into correlations in order to find *concurrence patterns* of activation among different spinal segments. For instance, simple pattern sp_i on spinal segment ss_j appear at the same time that simple pattern sp_k on spinal segment ss_l. The concurrence patterns found will be used to build a dictionary of concurrence patterns. The occurrence frequency of these concurrence patterns in the whole recording will help us to characterize the "state" of the functional connectivity between the segmental sets of dorsal horn neurons.

2.4 Detection of Temporal Recurrence Relations

The final step in the characterization of the state of functional interconnections between the dorsal horn neuronal ensembles will consist in the finding of temporal recurrence relations between concurrence patterns that appear in the recordings. For instance, the fact that concurrence pattern cp_i is usually followed by concurrence pattern cp_j will led as to define this temporal relation as a *temporal recurrence relation*. Again, a dictionary of common recurrence relations will be build, and the frequencies of these recurrence relations will be used to define the state of the spinal neuronal connectivity.

3 Conclusion

Disclosure of the patterns of intersegmental synchronization of spontaneous CDPs of different shapes and amplitudes seems a promising strategy to

characterize the functional interconnectivity between specific sets of dorsal horn neurons and how these patterns are changed under different pathological situations. Yet, the method needs to be improved to make it more selective and reduce the need for visual inspection. Our method presents the automatic selection of CDPs with proper characteristics of shapes and amplitudes and defines the concurrence of CDPs in the spinal segments. Now we are focused on the "concurrence patterns" of the spontaneous CDPs to interpret the spinal neuronal connectivity.

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