Information coding in early stages of the somatosensory system

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Abstract. This paper explores the information coding performed by the local circuit of the Cuneate Nucleus (CN). On the basis of physiological data, we have developed a realistic computational model and studied its output in response to different types of plausible cutaneous stimuli. Computer simulations show that (1) static stimuli are encoded in progressive spatio-temporal patterns made up of single-spike trains generated by each stimulated neuron, and (2) moving stimuli are encoded with a bursting discharge of those units responding to the leading edge of the stimulus. These results suggest that the role of CN could be to transform the stimulus representation in order to facilitate both discrimination and classification in later processing stages.

Key words: computational model, cuneate nucleus, information coding, somatosensory system

1. Introduction

Our interest is focused on the role of the Cuneate Nucleus (CN), a prethalamic structure. The cuneate and gracile constitute the Dorsal Column Nuclei (DCN), which receive input from primary afferent fibres (PAF) carrying somesthetic information from cutaneous receptors located in the limbs and trunk. The middle region of the DCN is the first stage of the Dorsal Column-Medial Lemniscus system, which processes fine tactile information. After being processed by the sensory receptors and the DCN, the cutaneous ascending information follows the Medial Lemniscus and make a relay in the Ventro-Postero-Lateral thalamic nucleus (VPL) (Kuypers and Tuerk, 1964) before reaching the primary somatosensory cortex.
The middle cuneate possesses two main types of neurons (Berkley et al., 1986): cuneolemniscal (CL), cuneothalamic or relay cells, and local neurons or interneurons. The former receive cutaneous input and project to the VPL nucleus, hence the name cuneothalamic; the later receive input from various sources (mainly cutaneous and proprioceptive) and exert their influence over the cuneothalamic neurons as well as other interneurons. In addition, the sensorimotor cortex exerts various influences over the DCN, including an excitatory input on the interneurons of the middle region of the DCN (Cheema et al., 1983).

A key point to better understand the cuneate function relies on the precise knowledge of the receptive field (RF) structure of the different cell types implicated in the CN circuitry. The current knowledge is limited mainly to CL cells. It has been recently shown that their RF has an excitatory centre and an inhibitory surround (Canedo et al., 2000). This spatial arrangement is generated through somatotopically organized afferent organization consisting of direct excitatory input on CL cells and GABAergic mediated inhibition from surrounding areas (Canedo et al., 2000). It has been demonstrated that when this circuit is constructed with realistic models of cuneate cells (Sanchez et al., 2003), it can perform edge detection as well as motion discrimination (Sanchez et al., 2002). Moreover, the relay cells with matched receptive fields monosynaptically activate each other through recurrent collaterals re-entering the nucleus, while inhibiting other projection neurons with different RFs (Aguilar et al., 2002). Their function could be to reinforce and synchronize the activity of CL cells in order to increase the robustness of the transmission of information to the VPL (Aguilar et al., 2002; Nunez et al., 2000). Finally, the presence of a second interneuronal type, the GLYCinergic (GLY) interneurons, which constitute about 30% of total neuronal population in the rat (Lue et al., 1997), introduces further complexity into the circuit. It is known that GLY neurons evoke facilitation of relay cells by inhibiting GABAergic interneurons (Aguilar et al., 2002, 2003).

The cuneate circuitry made up with the aforementioned neurons can perform a spatio-temporal coding of the cutaneous stimulus (Sanchez et al., 2004). Computational simulations show that the information associated to the stimulus could be transmitted to the thalamus in a progressive way, starting at regions with higher contrast, probably the more informative, and finishing at those with lower contrast. Furthermore, it has been shown that a clear dependency exists