Chapter II
Neural Mechanisms of Leg Motor Control in Crayfish:
Insights for Neurobiologically-Inspired Autonomous Systems

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ABSTRACT

Computational neuroscience has a lot to gain from invertebrate research. In this chapter focusing on the sensory-motor network that controls leg movement and position in crayfish, we describe how simple neural circuitry can integrate variable information to produce an adapted output function. We describe how a specific sensor encodes the dynamic and static parameters of leg movements, and how the central motor network assimilates and reacts to this information. We then present an overview of the regulatory mechanisms thus far described that operate at the various levels of this sensory-motor network to organize and maintain the system into a dynamic range. On the basis of this simple animal model, some basic neurobiological concepts are presented which may provide new insights for engineering artificial autonomous systems.

INTRODUCTION

In the second half of the last century, diverse sets of computer or robotic models have appeared in an attempt either to explain or reproduce various features of behavior. Although the majority of models first arose from mathematical approaches, the use of ideas originating from biological studies are now pre-eminent in the construction of artificial organisms designed to achieve a given task. However, although such robots perform quite well (*e.g.*, the salamander robot by Ijspeert *et al.*, 2007), the actual animal's performance always appears much more efficient and harmonious. This probably results from the continuous interaction between motor activity and sensory information arising from the surrounding environment (Rossignol *et al.*, 2006), in association with the perfect use of the biomechanical apparatus. It is thus primordial to understand fully the neural mechanisms involved in such a dynamic interaction to be able to implement realistic integrative algorithms in the design of computational models.

In this context, knowledge in invertebrate neuroethology has demonstrated unique advantages for engineering biologically-based autonomous systems (*e.g.*, Schmitz *et al.*, 2001; Webb, 2002). Although invertebrates are able to generate complex adaptive behaviors, the underlying neuronal circuitry appears quite simple compared to vertebrates. This chapter aims at presenting some basic neuronal mechanisms involved in crayfish walking and postural control involving a single key joint of the leg. Due to its relative simplicity, the neuronal network responsible for these motor functions is a suitable model for understanding how sensory and motor components interact in the elaboration of appropriate movement and, therefore, for providing basic principles essential to the design of autonomous embodied systems. In walking legs for example, sensory information is provided by simple sensory organs associated with each joint, and integrated by relatively small populations of neurons within the central ganglia (see Cattaert & Le Ray, 2001). Here, we describe, the encoding signals generated by a specific sensor that monitors both upward and downward leg movements, as well as the integrative mechanisms used to process these signals within the central nervous system (CNS). The many ways of tuning sensory-motor processes are then presented, which allow the system to adjust perfectly the motor command and, consequently, to generate fully adapted behaviors (Clarac et al., 2000). Some possible applications and future research directions will conclude this chapter.

MULTI-SENSORY CODING OF LEG MOVEMENTS

Crayfish possess an external skeleton that allows movements only at the various joints, the movement of each joint being coded by simple sensory organs. Among these, the leg coxopodite-basipodite chordotonal organ (CBCO) plays a pivotal role in the control of locomotion and posture, since it monitors vertical leg movements (Figure 1). This proprioceptor consists of an elastic strand of connective tissue in which sensory cells are embedded and whose function is comparable to that of joint receptors in mammals (Clarac *et al.*, 2000). The CBCO strand is stretched during opening of the second, unidirectional joint and released during closure, which corresponds respectively to downward and upward movements of the leg. The sensing apparatus of the CBCO is composed of 40 neurons that are equally divided into 20 stretch-sensitive and 20 release-sensitive neurons that code depression and levation of the leg, respectively (see Cattaert & Le Ray, 2001).

Coding Movement Parameters

Joint movement can be monitored either as a displacement of one segment relative to the other (dynamic parameter) or in terms of the relative position of both segments (static parameter). In