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Commentary

Via Autonomic Functions and Peptidergic Neuromodulation: Commentary on the *AIMS Neuroscience* Special Issue on "What is the Role of the Cerebellum in Emotional Processing and Behavior?"

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1. Introduction

The involvement of the cerebellum in affective brain activity has been demonstrated by various approaches including clinical and behavioral studies and brain imaging, but it is still difficult to identify precisely the role that the cerebellum plays in emotional processing and behavior. In two papers [1,2] in this special issue, many examples showing the likely involvement of the cerebellum in emotion regulation are reviewed, but in most cases, the exact role of the cerebellum is difficult to explain. To proceed further toward answering the question posed in the title, I suggest the following two directions that should be explored.

2. Two directions toward answering the question

2.1. To clarify which area of the cerebellum specifically represents emotion

The functional structure of the cerebellum devoted to motor function is hierarchically organized according to longitudinal zonal structures of the cerebellum [3]. Zones A (vermis) and B (paravermis) are devoted to the adaptive control of somatic reflexes, and zones C1-C3 (the intermediate parts of the cerebellar hemisphere) to the internal-model-assisted control of voluntary movements. Between zones D1 and D2 (the lateral parts of the cerebellar hemisphere), D1 is considered to be devoted to the control of motor actions (e.g., dancing, tool uses), whereas zone D2 (the most lateral part of the cerebellar hemisphere) is allocated to cognitive functions [4]. The thought process is a typical cognitive function, in which the prefrontal cortex manipulates ideas expressed in the cerebral parietal cortex. Zone D2 may support the thought process by providing an internal model of ideas, but how ideas are represented in the neural circuit is still unknown. With this longitudinal zonal organization

map, one can comprehend that cerebellar lesions lead to not only motor control dysfunction but also cognitive syndromes; however, where is emotion represented likewise?

Functional localization related to emotion has been shown for autonomic reflexes. In the vermis and flocculonodular lobe (parts of zones C1-C3), there are areas controlling cardiovascular homeostasis via the sympathetic nervous system [5]. In the first paper of this special issue [6], it is described that a discrete area of the cerebellar flocculus controls arterial blood flow associated with defense reactions. Lesions of the cerebellum at the flocculus, nodulus, and uvula impair these autonomic reflexes and their integrated functions, which will lead to impairment of physiological expressions of affective processes. The role of the cerebellum can be defined as the adaptive control of autonomic functions that support emotion regulation by a mechanism common to the adaptive control of motor functions.

2.2. Neuropeptide-containing cerebellar afferents mediate mood control

Mood impairment is a major clinical symptom associated with cerebellar diseases [7]. One may recall that some neuropeptides play a modulatory role in mood. For example, neuropeptide Y is involved in mood and anxiety disorders [8] and a decrease in its level is associated with an increased risk of suicide [9]. Corticotropin-releasing factor and galanin may also be involved in mood control as their antagonists exert antidepressant-like effects [10]. Recently, a number of neuropeptides have been shown to be substantially expressed in the cerebellum [11]. These neuropeptides are contained in beaded fibers, which project to the cerebellum diffusely and dispersedly [12]. This form of innervation is typical in neuromodulation [13], in which dispersed fibers do not convey information specific to individual fibers, but they govern the general activity of their target neurons as a whole. Thus, beaded fibers would switch the operational mode of their target neuronal circuit as a whole by neuromodulation.

As explained in the first paper of this special issue [6], the orexinergic system functions in the organization of neural circuits for anger and defense behavior; this case may provide a prototype mechanism for selecting an emotional behavioral repertoire via neuromodulation. Each neuropeptide may activate a certain unique set of neuronal circuits selected through the spinal cord, brainstem, and cerebellum, which jointly represent a specific emotion and behavior. The selected cerebellar portion is expected to control selected autonomic reflexes and their integrated functions in the spinal cord and brainstem. This mechanism could be an answer to the question posed in the title of this special issue.

Conflict of Interest

The author declares to have no conflict of interest.

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