

Cerebellar Control of Movement

Current concepts about the physiological functions of the cerebellum in the control of movement have been derived largely from examination of the deficits resulting from cerebellar lesions in experimental animals and humans. In one of the earliest major contributions, after extensive study of the effects of cerebellar ablations on posture and movement in animals, Luciani [1] concluded that three fundamental disturbances account for the signs and symptoms of cerebellar disease. These disturbances include atonia (diminished resistance to passive manipulation of the limbs); astasia (the jerky, intermittent character of movements); and asthenia (diminished power of movements). Building on these findings, but stemming principally from his own direct observations of the consequences of cerebellar tumors and gunshot wounds to the cerebellum during World War I, Gordon Holmes [2] described the disorders of movement resulting from cerebellar lesions in humans. He concluded that the fundamental disturbances are hypotonia (diminished resistance to passive manipulation of the limbs); static tremor (an oscillatory movement of a limb or the trunk when held motionless); asthenia (diminished power of movement); fatigability (difficulty moving repeatedly over long intervals); and astasia (jerky incoordination of movement). He subdivided the manifestations of astasia into dysmetria (a disturbance in the "range" of movement), errors in direction, disturbances in rate of movement, and kinetic tremor. He described other disorders appearing with more complex movements, including *adiachokinesis*, inappropriate associated movements, abnormal ocular movements, difficulties in standing and walking, and speech disorders. Holmes used the term, "decomposition of movement," to describe the degradation of smoothly performed complex movements into irregular, jerky components of these movements.

Despite major advances in cerebellar anatomy, physiology, and pharmacology since the time of Holmes' observations, there is continuing debate about the precise role of the cerebellum in the control of movement and the pathophysiology of the disturbances of movement after cerebellar lesions [3, 4]. It is generally agreed that defective motor coordination is a principal feature of diseases of the cerebellum and that the disturbances of coordinated movements are manifested by lack of smoothness during movement execution. Thus, for example, patients with cerebellar disorders show multiple peaks in the velocity profiles of movements [2]. Also, movements are often oscillatory, particularly as a limb approaches a target [5]. One possible explanation for these disturbances of coordinated

movements is disruption in the timing of the normal patterning of agonist and antagonist muscle activity in the course of a movement. In support of this idea, people with cerebellar disease have excessive amounts of agonist-antagonist cocontraction at movement onset [6]; improper timing of phasic bursts of activity in agonist and antagonist muscle pairs [7]; abnormal timing and intensity of the antagonist burst with movement [6, 8]; and delayed onset of antagonist activity [9]. Moreover, the time delay in tracking movements is increased, possibly because of an increase in reaction time for movement initiation [9]. These findings suggest that the cerebellum might be responsible for patterning the sequences of contraction of agonist and antagonist muscles, and raise the possibility that timing of these sequences may be faulty with cerebellar dysfunction. In support of this is evidence that the cerebellum contributes to the temporal aspects of motor and pattern generation by enhancing phasic activity in neurons within the motor cortex [8].

The notion that cerebellar disorders result principally from defective timing of sequential muscle contractions has recently received strong support [4, 7]; however, many other explanations of the pathophysiological processes resulting from cerebellar disorders have been proposed. The disturbances of movement with cerebellar lesions could result from poor utilization of feedback from joint proprioceptive, cutaneous, muscle sense, and visual feedback [9, 10]. Thus, muscle responses to perturbation of the limbs are abnormal in patients with cerebellar disease [11], and similar deficits are observed in response to perturbations of posture [9]. Evidence has been adduced also indicating that the cerebellum modulates reflex gain, including long latency reflexes, thereby maintaining effective joint compliance [9, 12]; compensates for inherent mechanical instability [13]; controls movements requiring multiple joints [14]; and calculates transformations between internal and external geometric plans for predictive coordination [15]. Another notion about cerebellar function is that it may contribute to movement by updating motor acts [16]. Through this mechanism, the cerebellum might compare certain motor functions such as limb position with the positions desired. The cerebellum might monitor this match and take actions to correct any mismatch. The detection of mismatches can be involved in the coordination of movement and in the adaptation of movement to new situations as well as in motor learning [3].

In light of the many current hypotheses about cerebellar function and the mechanisms underlying cere-

bellar dysfunction, the article by Manto, Godaux, and Jacquy [17] in this issue of the *Annals* is refreshingly direct and informative. The authors point out that a classic symptom of cerebellar disease is hypermetria, which consists of a movement that overshoots the target when a patient attempts to make a fast movement accurately. Such movements are known from previous studies to result from a burst of activation in an agonist muscle followed by a burst of activation in the antagonist muscle while the agonist is silent. This, in turn, is followed by another burst in the agonist muscle. The first burst of activity in the agonist muscle generates the torque, which accelerates the limb. The burst of activity in the antagonist muscle arrests the movement, and the final burst in the agonist brings the limb successfully to the site specified by the central nervous system.

Manto, Godaux, and Jacquy [17] investigated patients with cerebellar diseases in comparison with normal control subjects, all of whom were requested to make a rapid movement of a limb. The authors studied the effects of adding extra weight to the moving limb. The purpose of the study was to determine how the added weight influenced hypermetria and the associated pattern of electromyographical activity. The authors wished to develop a sensitive test to detect hypermetria in clinical practice and to understand more completely the role of the lateral portions of the cerebellum in programming ballistic movements. They demonstrated that adding mass to a moving segment increased the overshoot in patients with cerebellar disease and reduced it in the normal control subjects. This finding is in contrast to previous observations demonstrating reduced kinetic tremor in patients with cerebellar disease when mass is added to the limbs. These findings suggest that the pathophysiological mechanisms underlying hypermetria may be different from those responsible for kinetic tremor. Moreover, the findings are in contrast to the current general concept that the role of the lateral cerebellum in programming ballistic movements is restricted to the timing of agonist-antagonist activities. The studies suggest that the lateral portions of the cerebellum are involved in programming various aspects of antagonist activity, including not only the onset time of contraction of the antagonist muscle, but also the intensity of the contraction. In synthesizing the findings of the study, the authors suggest that the lateral cerebellum may compute the muscle activity needed for the braking function of the antagonist muscle, including the onset time and the amplitude, based on the initial position of the limb, the

position of the target, and the inertia to be overcome. Thus, the cerebellum can be deduced to be responsible for much more than a simple timing function. The simple but elegant observations by these authors provide interesting new insight into the mechanisms with which the cerebellum participates in the control of movement.

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References

1. Luciani L. Il cervelletto: nuovi studi di fisiologia normale e patologica. Le Monnier, Florence, Italy, 1891
2. Holmes G. The clinical symptoms of cerebellar disease and their interpretation. *Lancet* 1922;1:1177-1182, 1231-1237; 2:59-65, 111-115
3. Gilman S, Bloedel JR, Lechtenberg R. Disorders of the cerebellum. Philadelphia: F. A. Davis, 1981
4. Ito M. The cerebellum and neural control. New York: Raven Press, 1984
5. Gilman S, Carr D, Hollenberg J. Kinematic effects of deafferentation and cerebellar ablation. *Brain* 1976;99:311-330
6. Hallett M, Shahani BT, Young RR. EMG analysis of patients with cerebellar lesions. *J Neurol Neurosurg Psychiatr* 1975;38:1163-1169
7. Ivry R, Keele SW. Timing functions of the cerebellum. *J Cog Neurosci* 1989;1:136-152
8. Hore J, Flament D. Changes in motor cortex neural discharge associated with the development of cerebellar limb ataxia. *J Neurophysiol* 1988;60:1285-1302
9. Diener HC, Dichgans J. Pathophysiology of cerebellar ataxia. *Mov Disord* 1992;7:95-109
10. Gilman S. The mechanism of cerebellar hypotonia: an experimental study in the monkey. *Brain* 1969;92:621-638
11. Marsden CD, Merton PA, Morton HB, Adam J. The effect of lesions of the central nervous system on long-latency stretch reflexes in the human thumb. *Prog Clin Neurophysiol* 1978;5:334-341
12. MacKay WA, Murphy JT. Cerebellar modulation of reflex gain. In: Kerkut GA, Phyllis JW, eds. *Prog Neurobiol* 1979;13:361-417
13. Thach WT, Schieber MH, Mink J, et al. Cerebellar relation to muscle spindles in hand tracking. *Prog Brain Res* 1986;64:217-224
14. Thach WT, Goodkin HP, Keating JG. The cerebellum and the adaptive coordination of movement. *Ann Rev Neurosci* 1992; 150:403-442
15. Pellionisz A, Llinas R. Brain modeling by tensor network theory and computer simulation. The cerebellum: distributed processor of predictive coordination. *Neuroscience* 1979;4:323-348
16. Stein JF. Role of cerebellum in the visual guidance of movement. *Nature* 1986;323:217-221
17. Manto M, Godaux E, Jacquy J. Cerebellar hypermetria is larger when the inertial load is artificially increased. *Ann Neurol* 1994; 35:45-52