The Role of the Pediatric Cerebellum in Motor Functions, Cognition, and Behavior: A Clinical Perspective

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KEYWORDS

• Cerebellum • Motor coordination • Eye movements • Speech articulation • Language • Attention deficit hyperactivity disorder • Schizophrenia • Autism

KEY POINTS

- The pediatric cerebellum is important for processing, controlling, and modulating movement, cognition, and behavior.
- Pediatric cerebellar dysfunction causes poor coordination, increased variability, impaired accuracy, and tremor manifesting during limbs movements, walking, stance, talking, and eye movements.
- Pediatric cerebellar dysfunction results in cognitive and behavioral dysregulation.
- Cognitive and behavioral disorders, such as developmental dyslexia, attention deficit hyperactivity disorder, autism spectrum disorder, and schizophrenia, display cerebellar abnormalities/dysfunction.

INTRODUCTION

The cerebellum, Latin for small brain, weighs only about 10% of the adult human brain; however, it contains four times as many cerebral neurons. The cerebellum has undergone a rapid size increase in humans and apes that has been even faster than the rapid change in neocortex size.[1] This disproportionate increase in size is unlike that seen in other anthropoid primates where the neocortex and the cerebellum underwent similar expansion rates. Such expansion underscores the relative importance of the cerebellum in humans. Nevertheless, despite more than 100 years of scientific research, the function of the cerebellum remains elusive, but there is no shortage of possible theories on how the cerebellum works.

The anatomy of the cerebellum is discussed elsewhere in this issue. For the interested reader, physiologic cerebellar anatomy has been reviewed recently.[2] Basically, mossy fibers and climbing fibers provide excitatory inputs to the cerebellum via the superior, middle, and inferior cerebellar peduncles. Mossy fibers form synapses with granule cells, whereas climbing fibers synapse on Purkinje cells. Both fibers also send collaterals to the deep cerebellar nuclei. Granule cells form synaptic contacts with Purkinje cells via parallel fibers. Inhibitory outputs from Purkinje cells innervate the vestibular nuclei and the deep cerebellar nuclei. The latter constitutes the main output of the

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cerebellum and makes excitatory synapses on their targets. Other cells in the cerebellar cortex include Golgi cells, Lugaro cells, unipolar brush cells, stellate cells, and basket cells. They form interneurons within the cerebellar cortex.[2]

Different cerebellar regions have important roles in voluntary control of limb movements, ocular motor control, balance, walking, and nonmotor higher cognitive functions.[3] How does the cerebellum provide these functions?

The answer to this question has been addressed indirectly based on studies in patients with cerebellar damage. Computational modeling and experimental animal studies using pharmacologic, lesion, and genetic manipulations have also contributed further important insights. More recently, cerebellar transcranial direct current stimulation has provided a noninvasive approach to investigating cerebellar functions in health and disease.[4]

Movement abnormalities resulting from cerebellar impairment include poor coordination, increased variability, impaired accuracy, and tremor manifesting during limbs movements, walking, stance, talking, and eye movements.[5]

Two popular proposals on how the cerebellum functions are actively debated.[6,7] The first proposal states that the cerebellum contributes to motor and nonmotor control by acting as a timer. The second proposal states that the cerebellum functions by updating and/or storing an internal model of body dynamics.[8,9] In this model, the cerebellum essentially predicts the consequences of motor command on the body and its surroundings (eg, how a motor command will change the state of a limb or object position and velocity). A feedforward (ie, predictive and planned in advance) signal provides a fast response instead of relying on a visual or peripheral sensory feedback system with its attending long delay to ensure a real-time, correct, and appropriate motor response.[6] In addition, the cerebellum improves proprioception (ie, sensing the position of a limb in space in the absence of visual input) during active but not passive limb movement, through prediction.[10]

Other theories on cerebellar function include temporal and spatial sequence detection within the feedforward control mechanism,[11] tonic facilitation providing fine tuning of downstream target structures, and the initiation of coordinated compound movements.[12]

LIMBS MOTOR CONTROL

Parallel fibers link Purkinje cells and deep cerebellar nuclei, where single muscles are represented, thus providing a way of linking movements involving many muscles (ie, complex sequence of movements).[12] It is not known what signal the cerebellum uses to exert its modulatory control on movements. Candidate signals that may be used by the cerebellum include sensory information from the periphery or copies of the movement commands (efference copy) from the primary motor cortex. Another possibility that has not been proven is that the cerebellum is capable of generating motor commands that could lead a limb toward a desired target.[5]

Smooth and accurate execution of voluntary movements and adaptation to changing motor tasks depend on a healthy cerebellum.[13] Through trial and error, the cerebellum can learn and store different combinations needed for precise compound movements. Motor learning in children is not similar to adults.[14] Prior experience but not error size improves motor learning in young children. Various types of motor learning are achieved at different ages. In children up to 11 years of age, spatial adaptation matured at a slower rate than temporal adaptation in locomotion tasks that demanded walking on a split-belt treadmill with each leg's speed controlled independently.[15] Temporal adaptation (learning a new timing change) of a locomotor task matures by the age of 3 years.

Patients with cerebellar lesions can perform simple motor tasks, with incoordination and impaired initiation of movement appearing when compound complex movements are performed, especially at a rapid pace.[12] Cerebellar impairment cause greater dysfunction in predictive movements than in movements that require feedback (ie, visual or somatosensory feedback information).[5] However, the mechanism uses peripheral feedback functions suboptimally as the demand on it increases. Patients with cerebellar disorders have been shown to have proprioceptive deficits during active but not passive limb movements.[10] Cerebellar dysfunction affects fast movements to a greater extent than slow movements. In addition, the ability to adapt to novel changes in movements is impaired. Imprecise movements and errors in perception during active predictable movements following cerebellar impairment have been attributed to a malfunction in the internal models of body dynamics.[7] **Table 1** shows a list of signs seen in patients with cerebellar impairment.

OCULAR MOTOR CONTROL

The cerebellum is important for all types of eye movements and for ensuring fixation stability. The vestibulocerebellum is essential for gaze