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The cerebellum: Its role in language and related cognitive and affective functions

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ABSTRACT

The traditional view on the cerebellum as the sole coordinator of motor function has been substantially redefined during the past decades. Neuroanatomical, neuroimaging and clinical studies have extended the role of the cerebellum to the modulation of cognitive and affective processing. Neuroanatomical studies have demonstrated cerebellar connectivity with the supratentorial association areas involved in higher cognitive and affective functioning, while functional neuroimaging and clinical studies have provided evidence of cerebellar involvement in a variety of cognitive and affective tasks. This paper reviews the recently acknowledged role of the cerebellum in linguistic and related cognitive and behavioral–affective functions. In addition, typical cerebellar syndromes such as the cerebellar cognitive affective syndrome (CCAS) and the posterior fossa syndrome (PFS) will be briefly discussed and the current hypotheses dealing with the presumed neurobiological mechanisms underlying the linguistic, cognitive and affective modulatory role of the cerebellum will be reviewed.

1. Introduction

At the beginning of the 20th century, the cerebellum was regarded solely as a modulator of motor functions including diadochokinesia, tonus, coordination, and motor speech production (Babinski, 1902; Holmes, 1922; Luciani, 1891). This popular idea about the function of the cerebellum persisted throughout the 20th century. However, during the past three decades neuroanatomical, neuroimaging and clinical studies have provided evidence that the cerebellum is also involved in cognitive and linguistic processing. Studies with positron emission tomography (PET) (Petersen, Fox, Posner, Mintun, & Raichle, 1988, 1989) provided evidence for cerebellar involvement in nonmotor language functions revealing simultaneous activation of the supratentorial language areas and the right cerebellar hemisphere during language tasks. In addition, neuroanatomical studies revealed that the cerebellum is linked in a reciprocal way to the autonomic, limbic, and associative regions of the supratentorial cortex (Schmahmann, 2004). More specifically, cortical areas send information to the cerebellum via the basilar pons (Schmahmann & Pandya, 1997), and deep cerebellar nuclei send information back to prefrontal areas through dentatothalamic pathways (Middleton & Strick, 1997) (Fig. 1). More systematic neuropsychological investigations of patients with cerebellar lesions and the development of more sensitive cognitive tests allowed clinicians to identify a variety of linguistic, cognitive and affective deficits following cerebellar damage. This has resulted in a large number of case reports in which cognitive and linguistic symptoms are described following isolated cerebellar lesions. This review presents a concise overview of the modulating role of the cerebellum in language as well as in a variety of related cognitive and behavioral–affective processes.

2. The cerebellum and language

2.1. Verbal fluency and lexical retrieval

The first evidence to support the emerging view of a role for the cerebellum in linguistic functions (Leiner, Leiner, & Dow, 1986) was provided by PET activation studies which demonstrated that, in addition to Broca's area, the contralateral cerebellar hemisphere was actively involved in the production of semantically related verbs in response to visually presented nouns (Petersen et al., 1988, 1989). These studies for the first time showed that this consistent pattern of activation was not due to motor verbal responses but to nonmotor cognitive processes subserving semantic word association. Notwithstanding variations on the original task design, subsequent studies in healthy subjects consistently reported activation of the right lateral cerebellum during word generation tasks (Papathanassiou et al., 2000; Raichle et al., 1994). Hubrich-Ungureanu,

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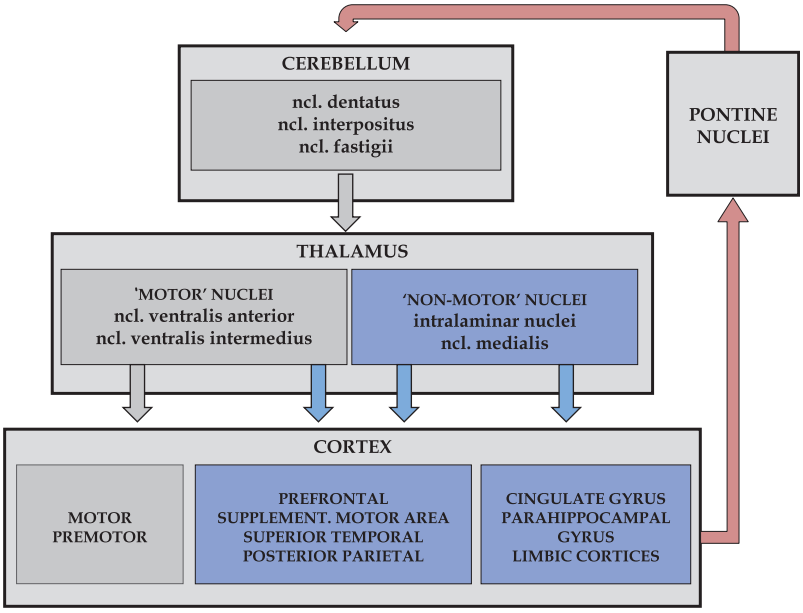

Fig. 1. Diagram depicting cerebello-cerebral connectivity network subserving cognitive and affective processes. The feedbackward or efferent loop originates from the deep nuclei of the cerebellum which project to the motor (gray arrows) and nonmotor (blue arrows) nuclei of the thalamus. In turn, the motor nuclei of the thalamus (ncl. ventralis anterior and intermedius) project to motor and premotor cortices (gray arrows) but also to nonmotor areas among which the prefrontal cortex, the supplementary motor area, the superior temporal and posterior parietal regions (blue arrows). The nonmotor nuclei of the thalamus project to the cingulate gyrus, the parahypocampal region and the limbic cortices (blue arrows). The feedforward or afferent system of the cerebello-cerebral circuit is composed of corticopontine and pontocerebellar mossy fiber pathways (red arrows) (Mariën et al., in press-a, in press-b; Schmahmann & Pandya, 1997). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Kaemmerer, Henn, and Baus (2002) examined the pattern of lateralized activations in a left and right-handed volunteer by means of functional magnetic resonance imaging (fMRI) during a silent verbal fluency task. In the right-handed subject with typical left hemisphere language dominance, regions of activation not only included the left fronto-parietal cortex but, as expected, also the contralateral right cerebellar hemisphere. In the left-handed subject with atypical right hemisphere language dominance a reversed pattern of language activations was found, reflected by crossed cerebral–cerebellar activations involving the right cerebral and left cerebellar hemisphere. The study concluded that cerebellar involvement in language processing is contralateral to the activation of the cerebral cortex, even under conditions of different language dominance. Recently, the role of the cerebellum in phonemic and semantic fluency tasks has also been investigated by means of Transcranial Magnetic Stimulation (TMS) using continuous theta burst stimulation (cTBS) (Arasanz, Staines, Roy, & Schweizer, 2012). Twenty-seven healthy subjects were randomly assigned to one or two groups for application of cTBS to the posterior-lateral cerebellum, and the left or right cerebellar hemisphere. Participants first participated in a phonological fluency task (F, A, S or P, R, W) followed by a semantic fluency task (animals or groceries). It was hypothesized that the number of category switches between the subcategories of words is a measure of mental flexibility, which is greatest during the first 15 s of the task. It was found that within the first 15 s of each trial, subjects with right cTBS had significantly lower switching scores after simulation. In addition, the study also provided additional evidence for the hypothesis that the cerebellum is involved in executive control via cerebello-cerebral connections to the frontal cortex (Gourovitch et al., 2000; Grabowski et al., 1996; Hubrich-Ungureanu et al., 2002; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Papathanassiou et al., 2000; Petersen et al., 1989; Raichle et al., 1994; Schlösser et al., 1998; Arasanz et al., 2012). Clinical studies of patients with cerebellar lesions have confirmed the implication of the cerebellum in word production. A good example of this is Fiez, Petersen, Cheney, and Raichle (1992) who described a 41-year-old, right-handed patient with semantic retrieval deficits, despite high-level conversational skills, after a vascular lesion of the right cerebellar hemisphere. In addition, Leggio, Solida, Silveri, Gainotti, and Molinari (1995), Leggio, Silveri, Petrosini, and Molinari (2000) compared patients with focal or degenerative left and right cerebellar lesions with controls using cluster analysis. Their results showed that cerebellar damage specifically affects phonological fluency while sparing semantic fluency. In addition there was no evidence of lateralization: reduced verbal fluency was noted in patients with either left or right cerebellar lesions (Cook, Murdoch, Cahill, & Whelan, 2004; Whelan & Murdoch, 2005). This is in contrast to Schweizer, Alexander, Gillingham, Cusimano, and Stuss (2010) who investigated 22 patients with chronic, unilateral cerebellar lesions, (12 patients with left and 10 patients with right cerebellar lesions): they found that the right cerebellar group produced significantly fewer words in a phonemic fluency task in comparison to the left cerebellar group and the healthy controls. Since right cerebellar lesions resulted in similar performance characteristics as left prefrontal lesions, it was suggested that the findings provide evidence for a lateralization effect, i.e. a prefrontal-right cerebellar system for the modulation of attention/executive demanding tasks.

2.2. Syntax impairment

Cerebellar damage may also be associated with grammatical and syntactic disorders. The occurrence of agrammatism was for the first time described by Silveri, Leggio, and Molinari (1994) who found an association between focal vascular damage of the right cerebellum and transient expressive agrammatism, characterized by the omission of free-standing grammatical morphemes, the omission of auxiliaries and clitics, and substitutions of bound grammatical morphemes. Single photon emission computed tomography (SPECT) scan of the brain showed a relative hypoperfusion in the entire left cerebral hemisphere, more stable and consistent in the left posterior temporal region. This patient's selective speech production impairment was interpreted as a "peripheral" disorder

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