The cerebellum and language functions

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ABSTRACT The interest in the role of cerebellum in cognitive functioning has been increasing in recent days, based on both theoretical considerations and empirical evidence. The first aim of this study was to provide an introductory overview of the recently acknowledged role of the cerebellum in a number of cognitive processes, with special emphasis on its implication in speech and language functions. For this purpose we present neuropsychological, anatomical and neuroimaging studies conducted over the past two decades which have shown that in human the cerebellum is implicated in diverse higher cognitive functions, such as language, memory, visuospatial skills, executive functions, thought modulation, and emotional regulation of behaviour. The second aim was to examine further the hypothesis of cerebellar involvement in verbal fluency providing evidence from a preliminary neuropsychological study. For this purpose two standardized verbal fluency tasks (a phonological task and a semantic task) were administered to four patients who suffered from cerebellar dysfunction due to hemorrhage or tumour at the right cerebellum area. Our findings showed that the verbal fluency deficit seen in cerebellar patients is linked both to phonological and semantic processing. Overall, the results of this preliminary study support the view of cerebellar contribution to verbal fluency, extending its role to cognitive aspects of language functions.

Key words: Cerebellum, Language, Verbal fluency.

Introduction

One of the most impressive parts of the human brain, named the cerebellum, has been underestimated for centuries. Traditional neurological tenets posit that the cerebellum coordinates skilled voluntary movements, and controls motor tone, posture, and gait. Perhaps the reason for which

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cerebellum has traditionally been underestimated is its low-level location in the brain, in contrast to the high-level location of the structures that are thought to subserve higher mental functions. Judged by its structure and by its external connections, the human cerebellum is an enormously impressive mechanism (Schmahmann, 2001). First of all, it contains more nerve cells (neurons) than all the rest of the brain combined. Second, it is a more rapidly acting mechanism than any other part of the brain, and therefore it can quickly process whatever information it receives from other parts of the brain. Third, it receives an enormous amount of information from the cerebral cortex, the highest level of the human brain, which is connected to the human cerebellum by approximately forty million nerve fibers (Leiner, Leiner, & Dow, 1991).

The cerebellum is a region of the brain that plays an important role in the integration of sensory perception and motor output. Many neural pathways link the cerebellum with the motor cortex -which sends information to the muscles causing them to move- and the spinocerebellar tract -which provides feedback to the position of the body in space (proprioception). The cerebellum integrates these two functions, using the constant feedback on body position to fine-tune motor movements (Leiner et al., 1991).

Because of this "updating" function of the cerebellum, lesions within it are not so debilitating as to cause paralysis, but rather present themselves as feedback deficits resulting in disorders in fine movement, equilibrium, posture, and motor learning. Initial observations by physiologists during the 18th century indicated that patients with cerebellar damage show problems with motor coordination and movement. Research into cerebellar function during the early to mid 19th century was done via lesion and ablation studies in animals. Research physiologists noted that such lesions led to animals' strange movements, awkward gait, and muscular weakness. These observations and studies led to the conclusion that the cerebellum was a motor control structure (Fine, Ionita, & Lohr, 2002).

However, anatomical, clinical, and neuroimaging studies conducted over the last ten to twenty years have shown that the cerebellum is implicated in diverse higher cognitive functions, such as language, memory, visuospatial skills, executive functions, thought modulation, and emotional regulation of behavior. The first aim of this study is to provide an introductory overview of the recently acknowledged role of the cerebellum in a number of cognitive processes, with special emphasis on its implication in language functions. The second aim was to examine further the hypothesis of cerebellar involvement in verbal fluency providing evidence from a preliminary neuropsychological study.

Cerebellum and cognition

Historically, the idea that the cerebellum may be involved in cognitive functions, apart from purely motor functions, was first given serious consideration in the late 1980's. During this period, some studies grounded the view that the cerebellum contributes to executive functions, such as mental planning, sequential reasoning, and mental operations closely associated with the functional role of the (pre)frontal cortex (Leiner, Leiner, & Dow, 1986; 1989). Keele and Ivry (1991) demonstrated that the cerebellum seems to act as an "internal clock" during any process requiring temporal computations.

The view that the cerebellum coordinates the direction of selective attention and as a consequence subserves the execution of cortically generated commands for the enhancement and inhibition of different sources of sensory information has been confirmed in a large series of behavioral, neurophysiological, and neuroimaging studies (see Akshoomoff & Courchesne, 1994; Akshoomoff, Courchesne & Townsend, 1997). Many studies further explored the role of the cerebellum in visuospatial and visuoconstructive procedures (Botez-Marquard & Botez, 1993; Botez-Marquard, Pedraza, & Botez, 1996). Experimental and clinical studies have demonstrated that the cerebellum is involved in many different components of memory such as procedural learning (eyeblink classical conditioning, motor adaptation learning, and motor skill learning), paired-associative learning, working memory, phonological short-term memory, and long-term memory (Marr, 1969; Molinari et al., 1997; Paulesu, Frith, & Frackowiak, 1993; Poldrack & Gabrieli, 2001). Most of the available data seem to corroborate the hypothesis that the cerebellum subserves cognitive operations at a modulatory level in between the cognitive processes per se and their relative executive phases (Silveri & Misciagna, 2000).

In addition, over the past twenty years a significant number of clinical and experimental studies have evidenced the crucial role played by the cerebellum in language functions. This role was evidenced for the first time in a PET study which showed cerebellar activation during language tasks (Petersen, Fox, Posner, Mintun, & Raichle, 1988). It was a surprising finding to many researchers, since the cerebellum was thought to be involved in motor functions only. As a consequence, researchers wondered whether the cerebellum would have anything to do with language. Since then, a number of papers have been published connecting language and other cognitive functions to the cerebellum (for a review see Justus & Ivry, 2001; Schmahmann, 2001).

Generally speaking, it is thought that the cerebellum and cerebral cortex *interact* for successful task performance. These tasks seem to include emotional, cognitive and language functions, in addition to the traditionally ascribed motor functions. In other words, the role of the cerebellum in the nervous system transcends appreciably the traditional notion of motor control. The cerebellum is also involved in sensory, cognitive, and affective processes, and this in a topographically precise manner. Damage to the cerebello-cortical loop brings about comportments that resemble those of injury to the cerebral cortical areas subserved by that loop. Rather than generating cognitive processes, the cerebellum is considered to modulate cognitive functions through the feedforward loop of the cortico-ponto-cerebellar system and the feedback loop of the cerebello-thalamo-cortical pathways. Since the 1980's the concept of cerebellar cognition has evolved from an amusing curiosity to a stimulating area of neuroscience research which includes studies of patients with cerebellar lesions, anatomical evidence for cerebellar language functioning and imaging studies involving PET, fMRI and ERPs, documenting cerebellar involvement in language processing.

Neuropsychological studies for cerebellar language functioning

The cerebellum can affect speech and language in a number of ways. One of the ways in which cerebellar contributions to language have been examined is through neuropsychological experimentation with patients who, either from progressive degeneration or focal stroke or tumours, have suffered a loss of cerebellar cortex. Falling within the more traditional motor domain of the cerebellum is its role in speech production. A symptom associated with cerebellar lesions is speech disturbance and cerebellar lesions disturb both articulation and phonation. Verbal expression is slow, monotonous, scanning, and often difficult to understand (Holmes, 1917). Darley, Aronson and Brown (1975) provided a detailed description of speech disorders in cerebellar patients and suggested to call this symptom ataxic dysarthria. Recent studies seem to suggest that ataxic dysarthria is mainly correlated with lesions in the superior paravermal region of the cerebellum (Ackermann & Hertrich, 2000).

A very frequent disorder arising after surgical removal of cerebellar tumors, especially in children, is transient mutism. It starts some days after the operation and persists for some weeks or months (Ersahin, Mutleur, Saydam, & Barcin, 1997; Van Dongen, Catsman-Berrevoets, & van Mourik, 1994). Since the cerebellum is mainly associated with edema of the brain stem (Pollack, 1997) it is probably due to a deactivation of the periaqueductal gray matter which is responsible for initiating vocalization and speech (Esposito, Demeurisse, Alberti, & Fabbro, 1999). These impairments have parallels in speech perception, suggesting a cerebellar role in speech that extends beyond production (Fabbro, 2000).

Clinical studies have concentrated on focal cerebellar lesions. A right cerebellar hemisphere lesion may have a role in the development of agrammatic expressive and expressive–receptive syndromes (Mariën et al., 1996; Silveri, Leggio, & Molinari, 1994; Zettin et al., 1997). This would take place through the phenomenon of the so-called "crossed cerebello-cerebral diaschisis" (Leiner et al., 1991; Mariën et al., 1996; Mariën, Engelborghs, Fabbro, & De Deyn, 2001). Crossed cerebello-cerebral diaschisis represents a phenomenon of temporary functional deactivation of areas of the frontal lobe subsequent to damage in the contralateral areas of the cerebellum.

The study of some patients with lesions in the right cerebellar hemisphere revealed that during language processing this structure also regulates some morphosyntactic and lexical components (Fiez, Petersen, Cheney, & Raichle, 1992; Mariën et al., 1996; Silveri et al., 1994; Zettin et al., 1997). In addition to these more purely phonological aspects of speech perception, the ability to access the mental lexicon may be compromised after cerebellar damage. Fiez et al. (1992) examined a patient who had suffered a cerebellar infarct in the right hemisphere. This patient generated incorrect and atypical responses across four word generation tasks (category, attribute, synonym, and verb generation). A similar pattern was found in four multilingual Italian patients studied by Fabbro, Moretti, and Bava (2000). However, not all investigators have reported this impairment. Helmuth, Ivry, and Shimizu (1997) did not find any lexical retrieval problems in a group of twelve cerebellar patients, including six with focal lesions in the right cerebellar hemisphere.

Another verbal impairment that has been associated with damage in the cerebellum is verbal fluency. For example, patients are asked to generate as many words as they can in one minute, with the words either beginning with a particular letter (phonological fluency) or belonging to a particular category (semantic fluency). Impairments in both kinds of fluency have been associated with cerebellar damage (Appollonio, Grafman, Schwartz, Massaquoi, & Hallett, 1993). In contrast to the results during single word lexical retrieval tasks, some authors have reported that the impairment is greater for phonological fluency than for semantic fluency (Bürk et al., 1999; Leggio, Silveri, Petrosini, & Molinari, 2000; Silveri & Misciagna, 2000).

Considerable attention has been focused on the possibility that the cerebellum might be part of a network involved in verbal working memory. For example, Silveri, Di Betta, Filippini, Leggio, and Molinari, (1998) studied a patient who suffered a temporary impairment in verbal working memory following the removal of the right cerebellar hemisphere. This patient not only had a reduced digit span but also showed unusual effects of two working memory manipulations common in the cognitive psychological literature. However, while some neuropsychological studies suggest a reduction in the overall capacity of working memory, as measured by digit span (e.g. Bürk et al., 1999), others have reported that the digit spans of patients with cerebellar lesions fall within the normal range (e.g. Fiez et al., 1992).

Silveri et al. (1998), after studying verbal short-term memory deficits in a patient with right cerebellar damage, reached the conclusion that the cerebellum is involved in the neuroanatomical loops (cortico-ponto-cerebellar and cerebello-thalamo-cortical loops) subserving the rehearsal system, a component of the working memory system which is responsible for inner repetition of verbal information (see Fabbro et al., 2000; Mariën et al., 2001; Silveri, & Misciagna, 2000)

Thus, it is clear that lesions of the cerebellum, particularly the right cerebellar hemisphere do produce aphasia-like symptoms and other language-related problems. This evidence provides support for the idea that the cerebellum, and particularly the right cerebellum, is somehow involved in language processing.

Anatomical evidence for cerebellar language functioning

At the neuroanatomical level, the cerebellum has extensive input and output connections projecting from and to the frontal lobes. The neural pathway from cerebral cortex to cerebellum has twenty million nerve fibers on each side. To appreciate what a torrent of information these fourty million fibers can send down from the cerebral cortex to the cerebellum, a comparison can be made with the optic fibers in the human brain. The optic tract contains approximately one million nerve fibers, which transmit to the brain the visual information that a human receives via the eyes. Forty times that much information can be sent from the cerebral cortex down to the cerebellum, including information from sensory areas of the cerebral cortex, from motor areas, from cognitive areas, from language areas, and even from areas involved in emotional functions (Leiner et al., 1991; Schmahmann, 2001).

This vast number of fibers receives high-level multisensory information input connections from association areas in the frontal, temporal and parietal lobes through the pontine nuclei ("mossy fibers") and the red nucleus – inferior olive system ("climbing fibers") (Leiner et al., 1991). It has extensive output connections to the frontal and prefrontal cortex (Broca's area, Brodmann 44 and 45) through the thalamus, in particular the ventrolateral nucleus (Leiner et al., 1991). Such a 'frontal lobe system' implicates the cerebellum in cognitive processes (e.g., word generation tasks) which require the activation of prefrontal language areas. A fundamental point about linguistic, cognitive and affective symptoms secondary to a cerebellar lesion is that most of the time these symptoms are subtle and thus difficult to detect by routine neuropsychological tests, in both adults and children. In addition, the symptoms of acquired cerebellar lesions of vascular origin tend to regress rather rapidly over time (Leiner et al., 1991; Mariën et al., 1996; Silveri et al., 1998; Silveri et al., 1994; Zettin et al., 1997), thus suggesting that a temporary functional deactivation of associative structures linked to the cerebellum may account for such deficits (Fabbro et al., 2000).

In addition, it has been shown that the left side of the cerebellum is connected to the right cerebral hemisphere and the right side of the cerebellum is connected to the left cerebral hemisphere, a fact which provides strong evidence that the cerebellum must be involved in more than just motor functions, and provides an explanation of the aphasia-like syndromes found in patients with right cerebellar lesions. Furthermore, from an evolutionary standpoint, neocerebellar growth paralleled that of frontal cortex with the frontal lobe being enlarged during evolution in parallel with the cerebellum (Fiez et al., 1992; Leiner, Leiner, & Dow, 1993). Since the prefrontal areas are responsible for higher cognitive functions, including language, this provides further evidence that these two brain areas could be closely linked and that they work together from a functional point of view.

Researchers have often wondered whether there are specific parts of the cerebellum which might be responsible for language functions. One of the areas thought to be involved in language processing is the dentate nucleus (Leiner et al., 1993). Neuropathologists, neurosurgeons and neurologists who examined human brains found that the primary target of the neural pathway from the dentate is the frontal lobe indicating that the frontal lobe functions must be closely connected with this specific part of the cerebellum. Further evidence provides the fact that when a lesion is intentionally created using a stereotaxic method in the dentate, it does not produce typical motor symptoms (Leiner et al., 1993).

Neuroimaging studies of cerebellar language functioning

Functional neuroanatomical studies using Positron Emission Tomography (PET) during the late 1980's demonstrated the selective activation of some cerebellar structures during language tasks (Petersen, Fox, Posner, Mintun, &, 1989). Over the past few years many neuroimaging studies (Desmond & Fiez, 1998; Fiez & Raichle, 1997) have attempted to explain more clearly the role of the cerebellum in overt and covert articulation and its involvement in some components of verbal working memory (such as the rehearsal system). These studies have also shown that the cerebellum is involved in learning of random associations, such as those between words and colours, and in word-finding tasks, more precisely, synonym selection.

Neuroimaging studies showed that some areas of the cerebellar hemispheres are activated during language tasks such as verb and noun substitution, and synonym generation (Desmond & Fiez, 1998; Fiez & Raichle, 1997; Petersen et al., 1989). Evidence from neuroimaging studies also indicate the possibility that the cerebellum might be part of a network involved in verbal working memory (see Cabeza & Nyberg, 2000).

Functional neuroanatomical studies suggest that the cerebellum has a role in sustaining language functions (see Fabbro, 2000). Patterns of cortical (notably Broca's area and supplementary motor area) and cerebellar activation are associated with word and rhyme-generation tasks, which require subjects to produce appropriate words or rhymes for given words (Klein, Milner, Zatorre, Meyer, & Evans, 1995; Mariën et al., 2001; Paulesu, Frith, & Frackowiak, 1993; Petersen et al., 1989).

Functional neuroimaging data (Klein et al., 1995; Raichle et al., 1994) have also shown cerebellar involvement in the acquisition of novel verbal production strategies. High cerebellar activation was observed in the acquisition phrases of a verb for noun generation task as well as synonym generation tasks. When the strategies are novel the activity of the different functional modules is not synchronised and a significant cerebellar contribution is required to progressively smooth out and speed up the generation process. Later on, when the task becomes so well learned that it can be performed automatically, cerebellar activation significantly decreases becoming indistinguishable from the activation during single word repetition.

fMRI studies have shown cerebellar involvement in verbal fluency tasks (Hubrich-Ungureanu, Kaemmerer, Henn, & Braus, 2002; Schloesser et al., 1998). Regions of activation were detected after performance of silent verbal fluency tasks and more specifically a verbal fluency MRI paradigm in right-handed persons showed a constant activation of the left fronto-parietal cortex and the right cerebellar hemisphere. PET studies using semantic tasks have also found right cerebellar and left frontal activation (Petersen et al., 1988; Raichle et al., 1994). In both the above kind of studies the level of activation in the areas mentioned was higher while searching for appropriate responses and not during response selection.

ERP studies have also showed a left frontal and right posterior cerebellar activation (Abdullaev & Posner 1997; Abdullaev & Posner 1998) using the same semantic processing tasks with the PET and fMRI studies, providing evidence that the cerebellum may be involved in language processing.

Theories concerning the cerebellum and language functioning

Various theories have been proposed in an attempt to explain the way the cerebellum might be involved in language processing. One of the earliest theories was that proposed by Marr (1969) who claimed that the cerebellum operates as a learning machine, encoding information as does a computer. Later on, Leiner and his colleagues (1993) developed a theory which claimed that the cerebellum improves the performance of the parts of the brain it is connected to. Their view was based on the idea that the cerebellum is connected to different parts of the cerebral cortex in different species. Therefore, since the cerebellum in humans is connected to language areas of the brain in the left prefrontal cortex, it improves or modulates language processing.

During the same time, Ito (1993) in his theory concerning cerebellum and language processing, claimed that there is no difference between thought and movement once encoded in the brain, since they both consist of neural firing. Thus, both movement and thought can be controlled with the same neural mechanisms. Furthermore, he described the cerebellum as "multipurpose learning machine which assists all kinds of neural control, autonomic, motor, or mental (verbal or nonverbal)".

More recent theories than the ones already mentioned are those proposed by Silveri and Misciagna (2000), Mariën et al., (2001) and Desmond, Gabrielli, & Glover, (1998). Silveri and Misciagna (2000) suggest that language deficits following right cerebellar lesions are not really aphasic disorders but are due to the impairment of some cognitive components (e.g., working memory) that are involved in language processing and may compromise some aspects of language production such as verbal fluency.

A different hypothesis is offered by Mariën and her colleagues (2001) who maintained that cerebellar lesions may provoke an aphasic syndrome. According to this theory, right cerebellar lesions may produce an aphasic syndrome similar to motor transcortical aphasia or dynamic aphasia as described by Luria. They suggested that this syndrome results from a disconnection of the neuronal circuits connecting the right cerebellar hemisphere to Broca's area (Brodmann areas 44 and 45) and the supplementary motor area. In this case, too, language recovery was correlated with a near normalization of the perfusion pattern in the left fronto-parietal area. More recent studies on children with cerebellar lesions (Riva & Giorgi, 2000) seem to confirm the role played by the right cerebellar hemisphere in language processing. Two children with acquired cerebellar lesions showed a reduced tendency to verbal expression, telegraphic spontaneous speech and word-finding difficulties (Riva & Giorgi, 2000).

A third recent theory (Desmond et al., 1998) tries to place cerebellar language functioning in the bigger context of language processing models. Its supporters observed, following neuroimaging studies, that the prefrontal lobes are involved with a semantic search and they are activated when the speaker is *searching* for appropriate responses, not during response *selection*. Since the cerebellum is active at the same time, they hypothesized that the cerebellum in some way mediates the semantic search process that is being carried out by the prefrontal lobes (Desmond et al., 1998).

A preliminary study of verbal fluency and the cerebellum

Central to the preceding discussion is the hypothesis that the cerebellum is involved in verbal fluency. This hypothesis is consistent with the neuroimaging as well as the neuropsychological evidence associating the cerebellum and language processing.

Verbal fluency deficits have been reported in cerebellar patients (Leggio et al., 2000; Mariën et al., 2001). Previous studies have shown that lesions of cerebellar structures impair the ability to generate lists of words according to a given rule and that this deficit is modality specific, affecting phonemic rule performances and sparing semantic ones, but there is little direct evidence on this issue. Verbal fluency was also among the largest impairments in a group of children with excised cerebellar tumours, particularly for those with damage in the right cerebellar hemisphere (Riva & Giorgi, 2000). This fluency impairment did not appear to be related to problems in speech production.

In view of the above findings, the aim of this preliminary study was to examine further the hypothesis of cerebellar involvement in language processing and more specifically in verbal fluency.

Case reports

For this purpose we studied four patients who suffered from cerebellar dysfunction due to hemorrhage or tumour at the right cerebellum area. No patient included in the study had history of neurologic illness or developmental learning disorder in childhood nor clinical or neuro-radiological evidence of extracerebellar disease and mini mental state examination (Tombaugh & McIntyre, 1992) was within the normal range.

Case 1 (B.G.): She was a 29-year-old right-handed female presented at the hospital with a three months history of headache and mild unsteadiness. On neurological examination she obtained a consciousness level of 15/15 at the Glasgow scale. CT scan revealed the presence of an auditory neurinoma which embodied half of the right cerebellar hemisphere.

Case 2 (K.H.): He was a 75-year-old right-handed male, admitted to hospital because of an acute headache after a lipothymia. He was confused and presented unsteadiness of gait. Axial computerized tomography of the brain revealed a large intraparenchymal hemorrhage at the inferior region of the right cerebellar hemisphere.

Case 3 (D.K.): He was a 61-year-old right-handed male presented with a three-month history of general slowing up, with unsteadiness of gait. CT scan revealed an astrocytoma involving the posterior area of the right cerebellar hemisphere.

Case 4 (E.S.): She was a 69-year-old right-handed female, admitted to hospital because of an acute headache after a lipothymia. Axial computerized tomography revealed a large intraparenchymal hemorrhage at the inferior region of the right cerebellar hemisphere.

Method

Two standardized verbal fluency tasks (Kosmidis, Vlachou, Panagiotaki, & Kiosseoglou, 2004) were administered to each subject. The first task required producing as many words as possible beginning with the Greek letters A (Alpha), Σ (Sigma), and X (Chi), (phonological task). The letters were selected based on the ratio of words in the Greek language starting with these letters relative to the total number of words in a Greek dictionary, which corresponds to the ratio of words in the English language beginning with the letters F, A, and S relative to the total number of words in an English dictionary.

The second task, administered immediately afterwards, required producing as many different words as possible belonging to the semantic categories for animals, fruits and objects (semantic task). We instructed participants to begin generating items verbally as soon as the researcher announced the letter or semantic category, and to avoid repetitions, variations of the same word, and proper nouns (on the phonological task). A 60 second period was given for each letter and for each category.

Results and Discussion

Table 1 shows the mean normative scores as well as patients' scores on verbal fluency tests. According to the Greek norms for the test, the patients in our study presented mild to severe deficits in both verbal fluency tasks. More specifically, two of our cerebellar patients (cases 2 and 4) presented severe deficits (Θ 2 SD) while the other two (cases 1 and 3) presented mild deficits (Θ 1 SD). This finding indicates that patients who suffer a damage at the inferior region of the right cerebellar hemisphere, such as

Table 1
Patients' performance and mean normative scores in verbal fluency tasks

	Semantic		Phonetic	
	M	**SD**	**M**	**SD**
Normative data for Case 1	42.7	10.9	26.5	9.6
Case 1	27.0[b]		15.0[b]	
Normative data for Case 2	40.0	7.9	25.5	10.2
Case 2	11.0[a]		4.0[a]	
Normative data for Case 3	40.0	7.9	25.5	10.2
Case 3	27.0[b]		14.0[b]	
Normative data for Case 4	40.0	7.9	25.5	10.2
Case 4	9.0[a]		2.0[a]	

a ≤ 2 S.D., severe deficit
b ≤ 1 S.D., mild deficit

cases 2 and 4 in our research study, are probably likely to present a more severe verbal deficit than those who have a damage which affects either half of the right cerebellar hemisphere, such as case 1, or the posterior area of the right cerebellar hemisphere, such as case 3.

These preliminary results suggest that all four cerebellar patients performed lower than normal people do in verbal fluency tasks, according to normative verbal fluency data stratified by age and education in the Greek population (Kosmidis et al., 2004). Our results are in accordance with previous research findings (Appollonio et al., 1993) which found impairments in both kinds of verbal fluency after cerebellar damage. However, they do not confirm the view (Leggio et al., 2000) that cerebellar damage impairs verbal fluency by specifically affecting phonological performance. More specifically, in the letter verbal fluency task our patients produced fewer words than normals which reveals that the verbal fluency deficit seen in cerebellar patients is linked to phonological processing. Letter verbal fluency tasks, such as the one used in our study, must be performed at the phonological level of word representation without reference to meaning. Therefore, when the subjects were asked to produce a list of word according to a phonemic rule the searching process is not automatic and requires the generation of a new strategy to make correct selections, to inhibit instructions and to keep a constant level of focused attention. Taking into account the stressed importance of the cerebellar circuits in acquiring new strategies, it is conceivable that cerebellar damage specifically affects letter verbal fluency because of the novelty of the strategy required (Desmond et al., 1998; Leggio et al., 2000).

In the semantic task they produced fewer words than normal for all three semantic categories they were given which reveals the active role the cerebellum plays in semantic verbal fluency. Generating semantically associated words reflects the person's capacity to generate words according to a given rule which is generally considered to depend on a close cooperation between verbal and executive abilities both controlled by the cerebellum. Our findings extend the functional role of the cerebellum in semantic tasks as it has been shown in previous studies which found that during semantic tasks there is an activation of the inferior lateral part of the right cerebellum, which projects to the left prefrontal language areas (Mariën et al., 2001).

Overall, the results of this preliminary study support the theory that the right cerebellar hemisphere assists the left cerebral hemisphere in helping an individual learn to make specific types of verbal associations. This supports growing evidence that the cerebellum, an area of the brain once thought to be involved only in the control of movement, also plays a role in processing speech and language.

Conclusions and further directions

In this article first we reviewed the evidence provided by previous neuropsychological, neuroanatomical and neuroimaging studies on cerebellar involvement in language functions and secondly we reported our findings from a preliminary study of verbal fluency in cerebellar patients.

Contrary to the belief that cerebellar involvement in language is limited to speech production, a variety of neuropsychological and neuroimaging studies in speech perception (see Mathiak, Hertrich, Grodd, & Ackermann, 2002), verbal working memory (Desmond & Fiez, 1998; Fiez & Raiche, 1997) and lexical retrieval (Fiez et al., 1992; Petersen et al., 1989) suggest that the cerebellum makes contributions that are not purely articulatory (for reviews, see Mariën et al., 2001; Silveri & Misciagna, 2000). This literature is part of a larger trend in cognitive neuroscience suggesting that the cerebellum makes contributions to cognition more generally, independent of motor demands (for reviews, see Justus & Ivry, 2001; Schmahmann, 2001). Previous research provided evidence in support of the view that the cerebellum is crucially implicated in a variety of non motor neurolinguistic processes and our study was meant to further explore the issue of language and cerebellum.

The fact that our understanding of the contribution of the cerebellum to neurolinguistic processes is currently still in a preliminary stage is essentially due to the historic neglect of the non motor role of the cerebellum. However, as compared to the first half of the 20th century, present knowledge of cerebellar anatomy and cerebellar functions has certainly increased. Above all, in the past twenty years the hypothesis has been advanced of a possible role of the cerebellum in the regulation of some cognitive functions, language and affective aspects (Fabbro, 2000). However, there are important questions remaining that may be addressed in future prospective studies on cerebellar involvement in language and cognitive functions. The relation of language or cognitive deficit with the site of the cerebellar lesion in a larger group of patients studied prospectively and in more detail could test the hypothesis concerning the topography of both sensorimotor and language or cognitive function within the human cerebellum. The nature and severity of executive functional impairment need to be quantified in more detail as they appear to be a central feature of the cerebellar cognitive affective syndrome in adults.

In addition, interpretations of cerebellar involvement in language and cognition often draw upon analogies to cerebellar involvement in motor tasks and studies (Desmond et al., 1998; Mariën et al., 2001) frequently provide converging evidence as to whether cerebellum provides a unique contribution to language and cognition or a secondary one. Therefore, there is a need for refinement of cognitive test methodologies and for the development of specifically adapted clinical investigation tools to further explore and delineate the exact role of the cerebellum in cognitive and neurolinguistic processes.

In conclusion, established knowledge about cerebellar architecture, cerebro-cerebellar connectivity and patterns of cognitive and motor deficits after cerebellar damage need to integrated and combined with the results from neuroimaging experiments in order to better understand the contribution of the cerebellum to cognition and more specifically to language functions.

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Παρεγκεφαλίδα και γλωσσικές λειτουργίες

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ΠΕΡΙΛΗΨΗ

Το ενδιαφέρον για το ρόλο της παρεγκεφαλίδας στη γνωστική λειτουργία έχει αυξηθεί στις μέρες μας, γεγονός που βασίζεται τόσο σε θεωρητικές σκέψεις όσο και σε εμπειρικά δεδομένα. Ο πρώτος στόχος αυτής της μελέτης ήταν να παράσχουμε μια εισαγωγική ανακεφαλαίωση του πρόσφατα αναγνωρισμένου ρόλου της παρεγκεφαλίδας σε έναν αριθμό γνωστικών διαδικασιών, με ιδιαίτερη έμφαση στην εμπλοκή της στην ομιλία και τις γλωσσικές λειτουργίες. Γι' αυτό το λόγο, παρουσιάζουμε νευροψυχολογικές, ανατομικές και νευροαπεικονιστικές μελέτες που διεξήχθησαν τις δύο τελευταίες δεκαετίες και οι οποίες έδειξαν ότι στον άνθρωπο η παρεγκεφαλίδα εμπλέκεται σε διάφορες ανώτερες γνωστικές λειτουργίες, όπως η γλώσσα, η μνήμη, οι οπτικοχωρικές δεξιότητες, οι εκτελεστικές λειτουργίες, η τροποποίηση της σκέψης και η συναισθηματική ρύθμιση της συμπεριφοράς. Ο δεύτερος στόχος ήταν να εξετάσουμε περαιτέρω την υπόθεση της συμμετοχής της παρεγκεφαλίδας στη λεκτική ευχέρεια παρέχοντας στοιχεία από μια προκαταρκτική νευροψυχολογική μελέτη μας. Γι' αυτόν το λόγο, δυο σταθμισμένες δοκιμασίες λεκτικής ευχέρειας (μια φωνολογική και μια σημασιολογική) δόθηκαν σε τέσσερις ασθενείς, οι οποίοι έπασχαν από παρεγκεφαλιδική δυσλειτουργία, οφειλόμενη σε αιμορραγία ή όγκο, στην περιοχή της δεξιάς παρεγκεφαλίδας. Τα ευρήματά μας έδειξαν ότι το έλλειμμα λεκτικής ευχέρειας που παρατηρήθηκε στους παρεγκεφαλιδικούς ασθενείς συνδέεται τόσο με τη φωνολογική όσο και με τη σημασιολογική επεξεργασία. Γενικά τα αποτελέσματα αυτής της προκαταρκτικής μελέτης ενισχύουν την άποψη της συνεισφοράς της παρεγκεφαλίδας στη λεκτική ευχέρεια επεκτείνοντας το ρόλο της σε γνωστικές όψεις της γλωσσικής λειτουργίας.

Λέξεις-κλειδιά: Παρεγκεφαλίδα, Γλώσσα, Λεκτική ευχέρεια.

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