Phonological grouping is specifically affected in cerebellar patients: a verbal fluency study

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Abstract

***Objectives*—Recent clinical and functional neuroimaging evidence points towards a cerebellar role in verbal production. At present it is not clear how the cerebellum participates in language production. The aim was to investigate the influence of cerebellar lesions on verbal fluency abilities with specific focus on the verbal searching strategies employed by patients with cerebellar damage.**

***Methods*—Twenty five patients with focal or degenerative cerebellar disease and 14 control subjects were tested in a timed verbal fluency task requiring word production under forced (phonemic or semantic) conditions. To analyse the verbal searching strategy employed, semantic and phonemic cluster analyses were also performed.**

***Results*—Performances of cerebellar patients were comparable with those of controls in the semantic task; conversely their performances were significantly impaired when tested in the letter task. Cluster analysis results showed that the verbal fluency impairment is linked to specific damage of phonemically related retrieval strategies.**

***Conclusion*—Cerebellar damage impairs verbal fluency by specifically affecting phonemic rule performances while sparing semantic rule ones. These findings underline the importance of the cerebellar computing properties in strategy development in the linguistic domain.**

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Recent data suggest that, besides motor control, cerebellar information processing plays an important part in functions such as learning, planning, judging time, emotional control, attention, and perception.[1] This knowledge has greatly widened the area of cerebellar studies.

Specifically, developmental, anatomical, clinical, and neuroimaging data are converging in clarifying the cerebellar contribution to language.[2] Clinical observations of autistic children showed reduction in size of the neocerebellum associated with language impairment.[3 4] Correlation of cerebellar volume with language abilities was found when comparing patients with Williams' and Down's syndromes.[5 6]

Indications of cerebellar influence on different aspects of linguistic processing were also reported in single case studies on patients with selective cerebellar damage. Mild naming deficits were found in a patient with idiopathic cerebellar degenerative disorder[7] and agrammatic speech was reported after a focal lesion of the right cerebellar hemisphere in the absence of other cognitive impairment.[8 9] Also, deficits in word association tasks were found after a right cerebellar lesion.[10] Verbal fluency deficits have also been reported in cerebellar patients.[7 10–17]

Functional neuroimaging data provide further support for a cerebellar role in linguistic functions.[18] Cerebellar activation, not linked to the motor aspect of speech, occurred during word association tasks such as verb for noun substitution,[19] synonym generation,[20] and recently, during word generation tasks according to a phonemic rule.[21]

Nevertheless, at present there is no agreement about the role of the cerebellum within the linguistic system.[22]

To better specify the contribution of the cerebellum to word generation, we investigated verbal fluency abilities in selected groups of patients with focal or degenerative cerebellar disease. In particular, verbal searching strategies were considered by analysing the use of bursts of words (clusters) semantically or phonemically related under forced conditions.

Methods

SUBJECTS

Twenty five patients with cerebellar lesions and 14 age and education matched controls were tested (see table 1 for patients' characteristics).

No patients included in the study had clinical or neuroradiological evidence of extracerebellar disease, the IQ score (assessed by the Wechsler adult intelligence scale) was above 80 and mini mental state examination was within the normal range. Some of these patients had already participated in clinical and experimental studies.[15 23 24]

Fourteen subjects without history of neurological or psychiatric illness, recruited from patients' relatives or volunteers, were selected as a normal control group (C). Mean age and education of all groups are reported in table 2. A one way analysis of variance (ANOVA) failed to disclose any significant group difference for age ($F_{3,35}=0.85$; NS) and education ($F_{3,35}=0.26$; NS).

All patients underwent a neurological examination and their motor impairment was quantified by a modified version of the cerebellar motor deficit scale proposed by Appollonio *et al*,[11] which ranges from 0 (absence of any deficit) to 42 (presence of all deficits to the highest degree) for total motor deficits and from 0 to 4 for dysarthria.

Table 1 Patients' characteristics

Group	Patient	Age (y)	Education (y)	Diagnosis	Motor score	Dysarthria score
LCB (n=13)	L1	41	5	Left medulloblastoma	12	1
	L2	81	5	Left PICA stroke	0	0
	L3	48	12	Left gangliocytoma	3	0
	L4	68	3	Left PICA stroke	7	0
	L5	37	5	Left vascular malformation	1	0
	L6	42	11	Left vascular malformation	4	0
	L7	41	12	Left vascular malformation	3	0
	L8	44	12	Left SCA stroke	1	0
	L9	67	5	Left PICA stroke	6	0
	L10	70	3	Left cyst	4	0
	L11	78	8	Left haemorragic stroke	7	0
	L12	29	12	Left haemangioblastoma	1	0
	L13	34	18	Left haemorragic stroke	7	0
RCB (n=6)	R1	70	8	Right AICA stroke	19	3
	R2	32	13	Right medulloblastoma	3	0
	R3	74	5	Right AICA stroke	7	0
	R4	60	5	Right metastatic lesion	1	0
	R5	42	18	Right embolic stroke	6	2
	R6	70	8	Right AICA stroke	19	2
ICA (n= 6)	I1	27	12	Cerebellar atrophy	12	2
	I2	59	8	Cerebellar atrophy	4	2
	I3	52	8	Cerebellar atrophy	6	1
	I4	72	12	Cerebellar atrophy	18	3
	I5	25	13	Cerebellar atrophy	9	2
	I6	31	8	Cerebellar atrophy	8	1

LCB group=patients affected by focal cerebellar lesions on the left side; RCB group=patients affected by focal cerebellar lesions on the right side; ICA group=patients affected by idiopathic cerebellar ataxia, the diagnosis of ICA was based on clinical indications of a purely cerebellar syndrome and on MRI evidence of atrophic pathology restricted to the cerebellum. AICA=anterior inferior cerebellar artery; PICA=posterior inferior cerebellar artery; SCA= superior cerebellar artery.

Table 2 Means (SD) of age and education in the four groups of subjects

Group	Age	Education
LCB	52.3 (17.84)	8.53 (4.61)
RCB	58 (17.2)	9.5 (5.08)
ICA	44.33 (19.44)	10.16 (2.4)
C	56.85 (17.08)	8.92 (3.22)

Experimental procedures were approved by the ethics committee of the Catholic University and written consent was obtained from each subject according to the Helsinki declaration.

TESTS

Two verbal fluency tasks were administered to each subject. The first task required producing as many words as possible, beginning with the letters F, A, and S, excluding proper names (letter task). The second task, administered immediately afterwards, required producing as many different words as possible belonging to the semantic categories for birds and furniture (semantic task). A 60 second period was given for each letter and for each category.

SCORING AND RATINGS

For each task and for each patient the following variables were considered: total verbal output, semantic and phonemic clusters, and cluster ratio.

TOTAL VERBAL OUTPUT

For the letter task, the total verbal output was scored by summing the number of words produced in the three trials. For the semantic task, the total verbal output was scored by summing the number of words produced in the two trials.

PHONEMIC AND SEMANTIC CLUSTERS

In the letter task, we considered as phonemic clusters two successive words with the same letters in the first and second positions (for example, *farfalla, fantasma*; fork, form) or two successive words which rhymed (for example, *alloro, adoro*; fake, flake). We considered as semantic clusters any pair of successive words belonging to the same semantic category (for example, *ananas, arancia;* apple, apricot) or two forms of a word (for example *amare, amatore*; sing, sang).

In the semantic task, we considered as phonemic clusters two successive words beginning with the same phoneme (for example, *canarino, condor;* cat, cow) or which rhymed (for example, *pappagallo, gallo*; cat, bat). We considered as semantic clusters any pair of successive words belonging to the same subcategory (for example, birds of prey: *falco, aquila*; hawk, eagle).

Two different examiners assessed the rate of phonemic and semantic clusters produced during both letter and semantic tasks.

CLUSTER RATIO

Because the two tasks had different durations (180 s *v* 120 s), to compare cluster production we calculated the "cluster ratios". These ratios were computed for each subject by dividing the total number of words produced on a test by the number of clusters produced on the same test. Thus, for each subject four cluster ratios were calculated (both phonemic and semantic cluster ratios for each of the two tasks).

STATISTICAL ANALYSIS

Metric units of the results of each group were compared by one way, two way, and three way ANOVAs. The score for dysarthria of the cerebellar motor deficit scale was treated as a covariate with the total verbal output for the letter and semantic tasks. When significant differences were found, post hoc comparisons among groups were assessed with Duncan's multiple range test.

Table 3 Mean (SD) of retrieved words and clusters in letter and semantic tasks

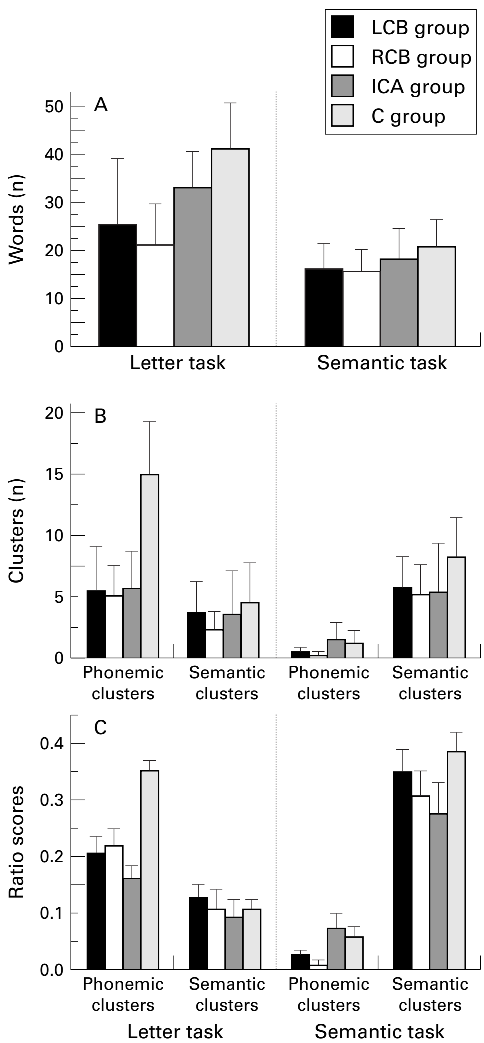
Group	Letter task	Semantic task	Letter task: Phonemic clusters	Letter task: Semantic clusters	Semantic task: Phonemic clusters	Semantic task: Semantic clusters
LCB	25.3 (14.0)	16.07 (5.4)	5.38 (3.7)	3.61 (2.6)	0.38 (0.5)	5.61 (2.6)
RCB	21.33 (8.3)	15.66 (4.6)	5.00 (2.5)	2.33 (1.3)	0.16 (0.4)	5.16 (2.4)
ICA	33.00 (7.7)	18.16 (6.5)	5.66 (3.0)	3.50 (3.6)	1.50 (1.3)	5.33 (3.8)
C	41.14 (9.4)	20.85 (5.8)	14.85 (4.4)	4.57 (3.1)	1.14 (1.0)	8.21 (3.3)

Results

TOTAL VERBAL OUTPUT

Mean values of retrieved words in letter and semantic tasks are reported in table 3 and the figure, A.

A one way ANOVA failed to show any significant group effect (F3,35=2.04; NS) in the semantic task; conversely, a highly significant overall group effect was present in the letter task (F3,35=6.8; p=0.0009). Post hoc analyses showed that, in the letter task, the two groups with focal lesions produced significantly fewer words than normal controls, whereas atrophic patients did not significantly differ from controls. No perseverations or inappropriate responses were detected in any of the four groups of subjects.



Mean values of (A) words produced in the letter and in the semantic tasks, (B) phonemic and semantic clusters for each task, and (C) phonemic and semantic cluster ratio for each task obtained by the four groups of subjects. Vertical bars indicate SDs. For statistical comparisons see text.

Phonemic and semantic clusters

All three groups of cerebellar patients as well as the control group produced a number of phonemic clusters greater than semantic clusters in the letter task and a number of semantic clusters greater than phonemic clusters in the semantic task (figure B).

Cluster mean values in letter and semantic tasks are reported in table 3.

In the letter task, a 4×2 ANOVA (group×cluster type) showed a significant main effect for group (F3,35=10.43; p=0.0000) and cluster type (F1,35=53.50; p=0.0000). Interaction was also significant (F3,35=18.30; p=0.0000).

In the semantic task, a 4×2 ANOVA (group×cluster type) showed a significant main effect for group (F3,35= 3.00; p=0.0432) and cluster type (F1,35=101.41; p=0.0000). Interaction was not significant (F3,35=1.92; NS).

CLUSTER RATIO

Cluster ratios (CRs) for each group in the two tasks are presented in figure C. They allow the comparison of overall performances of the different groups. A 4×2×2 ANOVA (group×task×cluster type) was conducted on the CR scores. There was a significant main effect for group (F3,35=4.57; p=0.008). The control group produced a significantly greater proportion of clusters overall (CR=0.23) than did the groups of cerebellar patients (LCB group (patients affected by focal cerebellar lesions on the left side): CR=0.17; RCB group (patients affected by focal cerebellar lesions on the right side): CR=0.16; ICA group (patients affected by idiopathic cerebellar ataxia): CR=0.15). There was also a significant main effect for cluster type (F1,35=44.54; p=0.0000), indicating that a significantly greater proportion of semantic clusters (CR=0.22) was produced overall than phonemic clusters (CR=0.14). A significant interaction (F3,35=3.29; p=0.0317) was obtained between group and cluster type. Post hoc contrast analyses showed that the three groups of cerebellar patients (LCB group: CR=0.116; RCB group: CR=0.116; ICA group: CR=0.119) produced a significantly lower proportion of phonemic clusters than the control group (CR=0.20). There was no significant difference between groups for the proportion of semantic clusters (LCB group: CR=0.24; RCB group: CR=0.21; ICA group: CR=0.18; control group: CR=0.25). A significant interaction (F1,35=118.15; p=0.0000) was also obtained between task and cluster type. Post hoc contrast analyses showed that a greater proportion of phonemic clusters (CR=0.23) was produced than semantic clusters (CR=0.11) on the letter task, and a significantly greater proportion of semantic clusters (CR=0.33) was produced than phonemic clusters (CR=0.04) on the semantic task. Although there was no significant interaction between group and task ($F_{3,35}$=0.81; NS), there was a significant three way interaction between group, task, and cluster type ($F_{3,35}$=3.06; p=0.0408).

Although the RCB group performed slightly worse than the LCB group on all the variables examined (figure), these differences did not reach significance.

MOTOR SCORE

Motor deficit scores are reported in table 1. All patients presented quite good motor performances. The highest motor impairment was recorded in the ICA group.

Treating the dysarthria score as a covariate with the total verbal output for the letter and semantic task, previous data were confirmed. In fact, a one way ANOVA with dysarthria score as covariate performed on the letter task showed a highly significant overall group effect ($F_{3,34}$=6.05; p=0.0020) while on the semantic task it failed to show any significant group effect ($F_{3,34}$= 2.27; NS).

Discussion

The present data show 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 rule ones. In addition, the cerebellar influence on verbal fluency is not lateralised; patients with either left or right focal damage presented reduced verbal fluency, although with a slight right prevalence.

When studying cognitive abilities in patients with cerebellar lesions it is necessary to be extremely cautious, taking into account possible influences of the cerebellar motor deficits on cognitive task performances. In the present study, motor functions were carefully evaluated with a specific cerebellar motor deficit scale. All patients in the present study exhibited very low motor impairment; the group with the highest motor impairment—that is, patients with cerebellar atrophy—presented the best fluency score. When the dysarthria score was treated as a covariate with the total verbal output for the letter and semantic tasks, all statistical differences were confirmed. Furthermore, the dissociation between letter task performances, which were significantly impaired, and semantic task ones, which were not different from the control values, shows that motor impairment itself does not account for the verbal fluency deficits.

Different studies on cognitive functions in patients with cerebellar damage reported verbal fluency deficits,[7 11 12 17] in agreement with the present findings. The present study allowed us to show that the verbal fluency deficit seen in cerebellar patients is specifically linked to phonological processing. The specificity of the cerebellar influence on phonological verbal fluency is further supported by the selective impairment in grouping words phonologically showed by cluster analysis data. The selectivity and uniformity of the impairment in patients with different cerebellar diseases confirm the cerebellar nature of the deficit.

Evidence from functional neuroimaging studies suggests that semantically driven and phonologically driven word retrievals are distributed functions that, at least partially, use different subprocesses depending on specific neural mechanisms.[19 21] As it was suggested that the same executive processes are active for beginning and monitoring all verbal fluency tasks, possible differences between letter and semantic verbal fluency would depend on the phonological or semantic nature of representations or on the specificity of the retrieval cues involved.[25 26] In performing any category fluency task it is necessary to activate a semantic system containing knowledge of physical and functional properties of objects. Activation of an initial and usually highly prototypical exemplar leads to automatic activation of closely related semantic neighbours.[25 27] By contrast, letter fluency must be performed at the phonological level of word representation without reference to meaning. Thus, it has to rely on an unusual means of word searching in the lexicon to form novel category neighbours.[25 27] Therefore, when asked to produce a list of words 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 intrusions, and to keep a constant level of focused attention.[27]

The specific effect of cerebellar damage on phonemic word retrieval and phonological clustering can be interpreted in the light of the suggested cerebellar role in planning, strategy formation, and learning of procedures.[14 24 28] As stated, whereas semantic verbal fluency is based on well known and usually employed strategies, letter verbal fluency requires the use of an unusual and novel searching strategy. Thus, taking into account the stressed importance of the cerebellar circuits in acquiring new strategies,[29 30] it is conceivable that cerebellar damage specifically affects phonological clustering because of the novelty of the strategy required.

Support for the hypothesis of cerebellar involvement in the acquisition of novel verbal production strategies also derives from functional neuroimaging data showing high cerebellar activation only in the acquisition phases of a verb for noun generation task.[31] When the task becomes so well learned that it can be performed automatically, cerebellar activation significantly decreases becoming indistinguishable from the activation during simple word repetition.[31]

The acquisition of a novel strategy of word retrieval requires correctly processing sequenced information. To obtain a correct phonemic cluster the subject has to select the correct word by sequentially coupling the last word with the new ones. In fact, to recognise the phonemic correspondence the last word sound/next word sound comparison must be correctly processed. To achieve this the subject has to keep the prototypical sound active within the working memory system and retrieve the word to be analysed from storage. The matching can be performed smoothly and speedily only if the two functions are well synchronised. It can be hypothesised that when the retrieval and matching strategies are well learned (semantic cue retrieval) the synchronisation is achieved without significant cerebellar activation; when the strategies are novel (phonemic cue retrieval) 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 matching. In the absence of the cerebellar input the matching can still be achieved correctly but it takes longer.

The cerebellar role in the cognitive domain seems to be similar to that which has long been recognised in the motor domain—that is, the cerebellum serves to keep functions steady around a homeostatic baseline and to smooth out performances.[32] This interpretation has already been advanced to explain other clinical findings, such as agrammatism,[8] sensory dysgraphia,[33] procedural learning impairment,[24] and verbal short term memory,[34] which were recently reported in cerebellar patients.

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