Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Preoperative language in children with posterior fossa tumours relative to typically developing peers: findings from the European CMS study

Aliene Reinders
University of Groningen
Cheyenne Svaldi
University College London
Annet Kingma
University Medical Center Groningen
Jonathan Kjær Grønbæk
Copenhagen University Hospital Rigshospitalet
Ditte Boeg Thomsen
University of Copenhagen
Karin Persson
Lund University
René Mathiasen
Copenhagen University Hospital Rigshospitalet
Christine Dahl
Copenhagen University Hospital Rigshospitalet
Andrea Carai
IRCCS Bambino Gesù Children's Hospital
Bianca Andreozzi
IRCCS Bambino Gesù Children's Hospital
Angela Mastronuzzi
IRCCS Bambino Gesù Children's Hospital
Barry Pizer
University of Liverpool
Colin Thorbinson
Alder Hey Children's NHS Foundation Trust
Kristian Aquilina
Great Ormond Street Hospital
Eelco Hoving
Princess Maxima Center for pediatric oncology
Marianne Juhler

Aarhus University Hospital

Roel Jonkers

University of Groningen

Vânia de Aguiar

vania.de.aguiar@rug.nl

University of Groningen

Research Article

Keywords: infratentorial neoplasms, posterior fossa syndrome, preoperative language impairment, language disorders, cerebellum, acquired childhood aphasia

Posted Date: November 4th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11430483/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background.

Language impairments after surgery and adjuvant treatment are common for paediatric patients with posterior fossa tumours (PFTs), but it remains unclear to what extent they are already present before treatment. We investigated preoperative language production in patients with PFTs to characterise tumour-associated language difficulties and their linguistic nature.

Method.

Narrative language samples from 56 children with PFTs and 56 age-, sex-, and language-matched typically developing controls were analysed. Twenty-four measures at the semantic, lexical, morphosyntactic, and phonological levels of language processing were clustered using principal component analyses and compared between children with PFTs and healthy controls, using linear models adjusted for age and language.

Results.

Before treatment, children with PFTs produced shorter narratives and received more prompting from the examiner than controls. They also showed poorer morphosyntactic performance characterised by reduced grammatical accuracy and finiteness, and showed poorer phonological performance characterised by more phonemic errors and incorrect consonant clusters. Exploratory analyses showed no effects of hydrocephalus and limited effects of tumour type, whereas children with hemispheric tumours performed worse than those with vermal tumours on several measures.

Conclusion.

Children with PFTs already show morphosyntactic and phonological differences before neurosurgical treatment, indicating that language difficulties in this population cannot solely be attributed to surgery or adjuvant therapy. These findings are consistent with a functional involvement of the cerebellum and its connections to language processing and underscore the importance of preoperative language assessment.

Introduction

Intracranial tumours are the most common type of solid tumours in children [1], with posterior fossa tumours (PFTs) making up around half of the cases [2]. The posterior fossa contains important brain structures, including the cerebellum, which has increasingly been found to be implicated in language processing [3]. The most common PFTs include medulloblastoma, pilocytic astrocytoma, ependymoma,

and brainstem glioma [4]. Treatment for PFTs typically involves a combination of resection, chemotherapy, and radiotherapy, with the latter two often serving as adjuvant treatments [5]. A common complication following surgery for a PFT is Posterior Fossa Syndrome (PFS), also referred to as Cerebellar Mutism Syndrome (CMS). It occurs in approximately 30% of patients [6–8], with emotional lability and a transient period of mutism or severely reduced speech as its cardinal symptoms [9]. The symptom of mutism or severely reduced speech has also been referred to as Postoperative Speech Impairment (POSI) [8]. Although survival rates have improved considerably over recent decades, survivors of PFTs continue to experience long-term cognitive and educational difficulties, including lower rates of academic achievement and employment [10]. Language difficulties also occur frequently in this population and include impairments in sentence formulation and syntax [11,12], expressive language [13], and word retrieval [14]. Research on language abilities in children with PFTs has, however, primarily focused on postoperative outcomes, often years after surgery [11,15–17]. At this point, it is difficult to disentangle the effects of the tumour and its characteristics from those of medical interventions and associated complications. Our study therefore focuses on language abilities prior to treatment, aiming to better understand the impact of the tumour itself and to explore whether language difficulties observed after treatment may already have been present at diagnosis.

The cerebellum and language

The cerebellum is located in the posterior fossa, a small cavity in the brain that contains densely packed and highly complex structures, including the brainstem. Through the brainstem, the cerebellum is connected with the cerebral cortex through reciprocal cerebro-cerebellar pathways, allowing information to be exchanged between cerebellar and cerebral regions, such as the left inferior frontal gyrus (Broca's area) and superior temporal cortex [3,18]. Although traditionally associated with motor control, the cerebellum is increasingly recognised for its functional involvement in higher-order cognitive functions, including language processing. Functional neuroimaging and neuromodulation studies in adults have for instance shown cerebellar involvement in language tasks targeting semantic processing [19], lexical naming [20] and learning [21], sentence processing [19,22], and phonological processing [22]. Activation is predominantly observed in the right cerebellar hemisphere, and more specifically in lobules VI, VIIa (Crus I and Crus II), and VIIb [23]. Importantly, emerging evidence suggests that these cerebellar regions do not just support domain-general processes recruited during language tasks, but form part of the language network itself. A recent fMRI study in adults identified language-responsive regions in the right posterior cerebellum, including a region spanning Crus I, Crus II, and lobule VIIb that showed a selective activation for language relative to a wide range of non-linguistic tasks [24]. Together with evidence that direct cerebellar lesions can result in language impairments in both adults and children [25–28], these findings support a functionally specific and causally relevant contribution of the cerebellum to language processing.

At the same time, the cerebellum forms part of the distributed language network through its reciprocal connections with supratentorial language regions [3]. Accordingly, cerebellar contributions to language may depend not only on the integrity of cerebellar language regions themselves, but also on their

communication with cerebral language areas. Within this framework, the cerebellum is proposed to support processes such as timing, prediction, and sequencing. Disruption of this communication may therefore be another way in which a posterior fossa tumour can affect language processing. This idea is further supported by evidence from patients with isolated brainstem lesions, a region not functionally implicated in higher-order language processing but critical for cerebro-cerebellar communication via cortico-ponto-cerebellar and cerebello-thalamo-cortical pathways [18,29]. Lesions affecting the brainstem have in adults been associated with broader cognitive and executive dysfunction [30,31], as well as language-specific impairments such as difficulties in word-finding [30,32], word comprehension [32], and verbal fluency [31]. Together, these findings suggest that language impairments associated with posterior fossa tumours may result both from direct involvement of cerebellar language regions and from disruption of their communication with supratentorial language areas.

Language impairments in children with PFTs

The majority of research on language difficulties in paediatric PFT patients has focused on the postoperative stage. A systematic review reported a wide variety of language impairments following surgery, including impairments in the domain of lexical semantics, morphosyntax, phonology, pragmatics, reading and spelling and verbal learning after surgery [33]. In addition to these post-operative studies, a small body of studies has examined language abilities prior to neurosurgical resection. A case report described a patient with a pilocytic astrocytoma who already presented with a developmental language delay two years prior to hospital admission [34]. Another study reported that, before surgery, 18% of patients showed impaired lexical naming abilities, 20.41% showed reduced mean length of utterance (MLU), and 25.57% experienced difficulties with verbal fluency [35]. A subsequent study expanded this cohort and investigated preoperative language impairments in relation to CMS, finding that 28.5% of patients presented with both preoperative language difficulties and CMS [36]. However, this study did not report on preoperative language impairments independent of postoperative outcomes. More recently, preoperative assessments revealed that 37% of patients presented with slow word finding, 24% with inaccurate word finding, and 16% with both, with the most frequent errors involving the use of semantically related words [37]. Another study showed that Swedish children with PFTs already demonstrate preoperative narrative difficulties at both macrostructural and microstructural levels, including reduced story content, shorter utterances, more grammatical errors, and a slower speech rate compared with typically developing peers [38].

Some of the aforementioned studies suggested that PFS with mutism and reduced speech may be associated with preoperative language impairments [35,36]. Building on these studies, we previously conducted an in-depth microstructural analysis of language, distinguishing children with mutism and reduced speech from those with habitual speech after surgery [39]. With respect to language, we found no differences between the two groups, although differences in speech intelligibility suggested that preoperative difficulties may be more apparent in the speech domain. However, as this study did not include a typically developing control group, it could not establish to what extent and in which domains children with PFTs as a group already showed language difficulties prior to surgery, irrespective of

postoperative outcomes. This is particularly relevant because postoperative language difficulties have been reported in children both with and without PFS [17].

Taken together, previous findings indicate that a proportion of children with PFTs already exhibit language difficulties before surgery, suggesting that these difficulties cannot solely be attributed to treatment. However, no previous study has comprehensively examined multiple levels of language to characterise the specific linguistic nature of these preoperative difficulties. Studying the presence and linguistic nature of language difficulties before surgery is important not only for distinguishing tumour-related dysfunction from treatment effects, but also for understanding how posterior fossa pathology may affect language processing prior to surgical intervention.

Current study

To address this gap, the present study aims to provide a comprehensive assessment of preoperative language abilities by examining multiple levels of language production and comparing performance at each level with that of typically developing children. This was achieved through language sample analysis, a method that has been shown to reliably distinguish children with PFTs from typically developing controls [15,17] and to differentiate between patient subgroups in the postoperative stage [40].

Theoretical models of language processing, including those proposed by Levelt [41] and Dell [42], assume that spoken language production involves multiple levels of processing. Across models, it is recognised that the language processing system stores and retrieves information across three distinct yet potentially interacting levels: the semantic-conceptual, lexical-phonological, and morphosyntactic level. The semantic-conceptual level concerns the activation and retrieval of conceptual and meaning-related information. The lexical-phonological level involves access to word forms stored in the mental lexicon (lexical processing) and the retrieval and sequencing of speech sounds required for speech production (phonological processing). At the morphosyntactic level, morphological and syntactic structures are generated according to grammatical rules. In the current study, we examined all these levels of language processing, while distinguishing between lexical and phonological processing, resulting in four levels of analysis: semantic, lexical, morphosyntactic, and phonological. These levels were examined using both standard language measures (e.g., MLU) and word-level properties that reflect processing at specific linguistic levels (e.g., imageability, frequency). This follows the critical variable approach described by Shallice [43], which proposes that psycholinguistic properties of words influence language performance. Because different psycholinguistic variables are associated with different levels of language processing, patterns of sensitivity to these variables can provide insight into the level at which an impairment may arise. For example, disproportionate difficulty with low-imageability words may point to impairment at the semantic level. This approach to characterising the levels of language processing underlying an impairment was also employed in spontaneous speech by our team [44] and others [45–47].

In the current study, we replicated the procedures described in Reinders et al. [39], examining 24 language variables across the four levels of language processing. At the semantic level, we examined the concreteness, imageability and familiarity of nouns and verbs, as well as the instrumentality of verbs used. At the lexical level, we assessed the lexical accuracy and diversity (type-token ratio; TTR), and the frequency and age of acquisition (AoA) of nouns and verbs. At the morphosyntactic level, MLU, grammatical accuracy and the use of finite verbs were assessed, as well as the transitivity, unaccusativity and regularity of verbs. Finally, at the phonological level, we assessed phonemic paraphasias, the production of consonant clusters and the length of nouns and verbs. A detailed description of the variables and their relevance as potential markers of language impairment is provided in the Supplementary Materials of Reinders et al. [39]. The analyses were conducted in children diagnosed with a PFT prior to neurosurgical resection and in a matched group of typically developing control children. By comparing the performance of patients diagnosed with a PFT with healthy control participants, we aim to characterise language differences associated with PFTs before any treatment has taken place, as well as to understand the underlying linguistic mechanisms driving the impairments. This knowledge is linguistically relevant, as it contributes to a better understanding of the underlying mechanisms of language production and the involvement of the cerebellum therein, and clinically relevant, as it may help to characterise preoperative language changes associated with posterior fossa tumours and thereby support timely clinical evaluation and intervention.

Method

Participants

Patients. This study included 56 children who underwent PFT surgery and were enrolled in the European Study of CMS [48]. The European study of CMS is a prospective multicentre cohort study currently involving 14 countries, in which participating treatment centres collectively contribute demographic and clinical data on children undergoing surgery for a PFT. To date, data from more than 1,000 patients have been included in the database. The current analyses included 33 of the 34 patients previously analysed by Reinders et al. [39] (one was excluded because no suitable control was available; see *Control participants*), together with an additional 23 patients meeting the inclusion criteria. An overview of the sample formation process is presented in Figure 1. Participants were recruited from treatment centres in the Netherlands, the United Kingdom, and Italy and spoke Dutch, English, and Italian, respectively, as their first language. Patients with previously documented neuropsychological, speech or language impairments were excluded, as it was not possible to reliably distinguish between difficulties associated with tumour growth and those resulting from an independent developmental disorder. To characterise the patient group, several clinical measures were extracted from the patient reports, including tumour location (categorised as brainstem involvement; fourth ventricle without brainstem involvement; cerebellar vermis without brainstem or fourth ventricle involvement; and cerebellar hemisphere without brainstem, fourth ventricle, or vermis involvement), tumour histology (medulloblastoma, pilocytic astrocytoma, ependymoma or other tumour types), and preoperative hydrocephalus (absent or present), dysarthria and oculomotor difficulties (originally reported on a three- or five-point scale, but for the

current study reported as absent or present), and POSI status (habitual speech, mutism or severely reduced speech).

Control participants. Patients were individually matched to 56 typically developing children based on age, language, and, where possible, sex. See Appendix A for the demographics of each matched control. Italian and Dutch control children were recruited for the purpose of this study and all attended regular education. Exclusion criteria for Dutch and Italian controls were (1) severe articulatory problems, (2) language disorders of any kind, (3) psychiatric and neurological disorders, (4) the use of psychopharmacological medication, (5) uncorrected visual or hearing impairments and (6) clinical score on a general cognitive or sentence repetition task (see Method – Materials). For control participants from the UK, we included children from the normative sample collected for the purpose of standardising the Expression, Reception and Recall of Narrative Instrument (ERRNI) [49], whose demographic and language data are publicly available in Open Science Framework [50]. Participants included in the normative sample spoke English as their first language at home and did not have any special educational needs [49]. In Open Science Framework, the exact ages of the participants were not available, but were expressed as an age band. The age bands were 3 months for 4- and 5-year-olds (e.g., 4;0-4;2, 4;3-4;5), 6 months for 6-year-olds (e.g., 6;0-6;5, 6;6-6;11), one year for 7- to 9-year-olds (e.g., 7;0-7;11), and two years from the age of 10 (e.g., 10;0-11;11). Patients were matched to a control corresponding to the same age band. To statistically assess whether age differed between groups, the middle age of each control age band was taken as the age of the control participants (e.g., 4;1 for the age band of 4;0-4;2). One 3;9-year-old English patient had to be excluded because the normative data only included control participants from the age of 4;0. For three male and three female patients, no age- and language-matched control of the same sex was available. Those patients were therefore matched to an age- and language-matched control of the opposite sex, to allow for maximal inclusion of participants, and still achieve sex matching across the sample.

Materials and procedures

Patients. Clinical and demographic background information and language samples were obtained through the database built within the European Study of CMS [48]. Speech samples of the patients were collected before surgery by clinicians or speech pathologists using the ERRNI – Fish Story [49]. In this task, participants silently viewed a picture storybook from beginning to end, whereafter they were asked to go through the book again and tell the story. Narratives were elicited by speech and language pathologists, nurses, or physicians, following standardised instructions based on the ERRNI testing manual and provided by a speech and language pathologist. Examiners were instructed to provide minimal prompts. In this study, the ERRNI picture book was only used as a tool to obtain spontaneous language samples across different languages, rather than to assess performance against established norms. The narratives were audio-recorded for subsequent analysis.

Controls. Data from Dutch and Italian control participants were collected for the purpose of this study. Before participation, children and parents were informed about the study and asked to give their

consent. Thereafter, a testing session of approximately 45 minutes administered by a well-trained examiner took place in a quiet room. To determine whether participants could be included as typically developing controls, several standardised tasks were administered to assess non-verbal cognitive abilities, including visuospatial processing and non-verbal reasoning, as well as general language abilities using sentence repetition. See Table 1 for an overview of the tasks per language and age group. To collect a language sample, the same procedures were applied as for the patients, using the ERRNI - Fish Story [49]. The testing session was audio-recorded for further analysis.

Demographic background information and transcriptions of the narrative language samples from the English control participants were downloaded from Open Science Framework and stored for further analysis.

Table 1 *Background tasks administered in Dutch and Italian control participants*

	Cognitive tasks	Age (in years)	Language tasks	Age (in years)
Italian	WPPSI-IV Object Assembly [51]	3-5	NEPSY-II Ripetizione di Frasi [52]	All
	Raven's Standard Progressive Matrices [53]	6+		
Dutch	WNV-NL - Recognition [54]	3-6	CELF Preschool-2-NL Sentence Repetition [55]	3-4
	WNV-NL - Spatial Orientation [54]	7+	CELF-5-NL - Sentence Repetition [56]	5+
	WNV-NL - Matrix reasoning [54]	All		

Note. WPPSI-IV: Wechsler Preschool and Primary Scale of Intelligence - Fourth edition; NEPSY-II: Developmental NEuroPSYchological Assessment - Second Edition; CELF preschool-2: Clinical Evaluation of Language Fundamentals

Scoring

The scoring of Dutch and Italian background tasks followed the standard procedures described in the corresponding test manuals [51–56], and percentile scores were extracted for all tasks. If a participant scored below the 10th percentile on any of the background tasks administered at that age, they were excluded from further analysis.

For the narrative data, the audio-recorded samples from patients and Dutch and Italian controls were transcribed using the ELAN software [57], following the Spontaneous Speech Analysis Procedure (STAP) [58] and ERRNI guidelines [49]. An utterance was excluded from analysis if 20% or more of the words in that utterance were unintelligible or hard to understand, if it was an imitation of what the examiner said,

if it was a comment unrelated to the story, or if it was a question directed at the examiner. All remaining utterances were included for further analysis. Scoring of the Dutch and Italian samples followed the same procedures as described by Reinders et al. [39]. Scoring of the English samples largely followed the same procedures, although there were some slight changes (see section *Adapted procedure English samples*).

From the above-described procedure to prepare the samples for analysis, several global sample characteristics were derived, including language sample size in *number of words* and *number of utterances*, and the *percentage of unclear speech* (i.e., the percentage of utterances that had to be excluded from further analysis because they contained 20% or more unintelligible or hard to understand words). Additionally, we calculated the *percentage of prompted utterances* (i.e., the percentage of utterances produced in response to a prompt or question by the examiner), since, although examiners were instructed not to prompt the child in telling the story, the examiners frequently provided help. Thereafter, the samples were scored on 24 linguistic variables, grouped across the four linguistic levels, following the approach developed by Svaldi et al. [17]. Table 2 provides an overview of the variables included in our analysis. Values for the psycholinguistic variables *concreteness*, *familiarity*, *imageability*, *Age of Acquisition* (*AoA*), *word frequency* and *word length* were extracted from several Dutch, English and Italian databases. An overview of these databases can be found in Appendix B. For Italian, no database for word length in phonemes was available, so word length was determined by counting the number of phonemes contained in each noun or verb.

Table 2 *Overview of language measures used for statistical analyses*

Level of language processing	Standard language sample measures	Additional (psycho)linguistic variables
Semantics	-	Concreteness*
		Familiarity nouns
		Imageability*
		Verb instrumentality (proportion)
Lexicon	Lexical diversity (TTR)*	Age of acquisition*
	Lexical accuracy (percentage)	Word frequency*
Morphosyntax	Mean utterance length (in words)	Verb transitivity (proportion)
	Grammatical accuracy (percentage)	Unaccusativity (proportion /intransitives)
	Finiteness Index	Verb regularity (proportion)
Phonology	Phonological errors	Word length (in phonemes)*
		Cluster index

Note. Variables marked with * were analysed separately for nouns and verbs.

Adapted procedure English samples

Because control data from the United Kingdom were collected during the standardisation process of the ERRNI Fish story task, some of the scoring procedures and analyses described in the original protocol by Reinders et al. [39] could not be carried out or required adjustments. During the standardisation process by Bishop, the samples were cleaned to prepare them for MLU calculation. As a result, the data no longer contained the following elements: (1) utterances that were produced in response to a prompt, (2) disfluencies such as hesitations (e.g., “uh”), interjections (e.g., ‘well’), self-corrections (e.g., “the fish, no, the boy is walking”) and repetitions (e.g., “the the boy is walking”), and (3) phonological errors (e.g., “tat” instead of “cat”). Therefore, for English patients, all utterances produced in response to a prompt from the examiner and all disfluencies were removed from the sample. Consequently, for both patients and controls, *Type Token Ratio* (*TTR*) *nouns* and *TTR verbs* were calculated only on nouns and verbs produced in non-prompted utterances and without those that were part of disfluencies. In addition, English patients and controls were not scored on the *percentage of prompting*, *phonological errors* and *cluster index*, and were therefore excluded from the analyses at the phonological level (see section *Analysis* for further explanation). All remaining variables were scored and analysed in the same way as the Italian and Dutch samples.

Analysis

Analyses followed the approach developed by Svaldi et al. [17] and subsequently adopted in Reinders et al. [39]. For a more detailed description of the analyses and their rationale, please refer to those papers. To reduce the large number of variables included in our linguistic analysis, as a first step, we performed a principal component analysis (PCA) for each level of language processing. In the PCA, variables that explain variability in the data in a similar way cluster together into components, each variable with its own loading. Since a PCA cannot be performed with missing values in the dataset, the English participants were excluded from analyses at the phonological level, as their samples contained missing values for the variables *phonological errors* and *cluster index*. The PCA at the phonological level was therefore performed with the remaining 32 Dutch and Italian patients. Furthermore, the suitability of the data for PCA was assessed using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. Variables with insufficient KMO values were excluded from the PCA and analysed separately (see Reinders et al. [39]). At each level of language processing, components with an eigenvalue > 1.0 were retained for further analyses. As described in Reinders et al. [39], PCA outputs were used as a guideline in deciding which variables could be combined at each level of language processing. Only those variables with a significant contribution to a given component were standardised into z-scores and averaged. In the current paper, however, not only variables with a significant contribution to the component were combined, but components were constructed including all variables and their specific loading into the component, as this better reflects the impact of all variables and their relatedness on a certain level. Still, variables with a loading into the component of 0.45 or higher were considered the primary contributors to the interpretation of that component. Analyses in Reinders et al. [39] were rerun following these procedures, and results did not change.

After grouping the variables, linear models [59] were constructed for the global sample characteristics, the components extracted from the PCA and separate variables not included in the PCA due to insufficient KMO values. Each model included *group* (patient or control) as a predictor and *age* and *country* as covariates. Country was included as a covariate to account for systematic differences between the language groups. Country-specific effects were not examined further, as country was not a primary variable of interest in this study and also captured other sources of variation, such as differences in recruitment centres and examiners. Additionally, for components/variables including TTR nouns or verbs, *number of words* was added as a covariate, given TTR's sensitivity to sample size [60]. As additional exploratory analyses, the effects of *tumour type* (limited to pilocytic astrocytomas and medulloblastomas, given the small number of patients with other tumour types) and *tumour location* (brainstem involvement; fourth ventricle without brainstem involvement; cerebellar vermis without brainstem or fourth ventricle involvement; and cerebellar hemisphere without brainstem, fourth ventricle, or vermis involvement) on language performance were examined within the patient group using linear models adjusted for age, sex, and country. For tumour location, overall effects were assessed using Type III ANOVA, followed by Tukey-adjusted post-hoc pairwise comparisons for significant and exploratory trend-level effects. Statistical analyses were carried out in RStudio [61].

Results

The total sample consisted of 56 patients and an equal number of control participants. Table 3 presents the clinical and demographic characteristics of the groups included in this study. See Appendix A for an overview of individual patient characteristics and the age and sex of each matched control participant.

Table 3 *Demographic and clinical background information per group*

	PFTs (n=56)	Controls (n=56)	χ^{2a}/t	*p*
Age (in YY;MM)			*t* = -0.152	.880
M (*SD*)	9;11 (3;6)	9;10 (3;5)		
Range	3;5-17;8	3;5-17;6		
Sex, *n* (in %)			χ^2 = 0.037	.848
Male	33 (59)	32 (57)		
Female	23 (41)	24 (43)		
Country, *n* (%[b])				
Italy	16 (29)	16 (29)		
The Netherlands	16 (29)	16 (29)		
United Kingdom	24 (43)	24 (43)		
Tumour location, *n* (%[b])				
BS involvement	14 (25)			
FV without BS	24 (43)			
VM without BS or FV	7 (13)			
CH without VM, BS or FV	10 (18)			
Unknown	1 (2)			
Tumour histology, *n* (%)				
Medulloblastoma	20 (36)			
Pilocytic astrocytoma	23 (41)			
Ependymoma	3 (5)			
Other	7 (12)			
Unknown	3 (5)			
Pre-op dysarthria, *n* (%[b])				
Present	8 (14)			
Absent	40 (71)			
Unknown	8 (14)			
Pre-op hydrocephalus, *n* (%)				

Present	35 (62)			
Absent	21 (38)			
Pre-op oculomotor difficulties, *n* (%)				
Present	23 (41)			
Absent	24 (43)			
Unknown	9 (16)			
POSI status, *n* (%)		-	-	-
Habitual speech	36 (64)	-	-	-
Reduced speech	5 (9)	-	-	-
Mutism	10 (18)	-	-	-
Unknown	5 (9)	-	-	-

Note. Y;M = Age in years and months; BS = brainstem; FV = fourth ventricle; VM = vermis; CH = cerebellar hemispheres, Other = atypical teratoid/rhabdoid tumour and other tumour types; Pre-op = Preoperative; POSI = Postoperative Speech Impairment.

[a]A chi-square test was performed using Monte Carlo simulation (10,000 replicates) to account for small cell counts and limited sample size.

[b]Percentages do not total exactly 100 because of rounding.

Global language sample characteristics

In Table 5, the results of analyses on several global sample characteristics are presented, showing the effects of the covariates age and country, as well as the predictor group. A significant effect of group was found for sample size in number of words after controlling for age and country (β = -39.42, *SE* = 10.17, $p < .001$), with patients producing shorter samples than the control group. For the total number of utterances, no group effect was found, although it neared significance (β = -2.13, *SE* = 1.08, $p = .051$). Additionally, after adjusting for age and country, group was a significant predictor of prompted utterances (β = 11.37, *SE* = 4.90, $p = .024$). No significant main effect of group was observed for percentage of unclear speech (β = 0.97, *SE* = 1.09, $p = .375$).

Linguistic analysis

Principal Component Analysis

Four PCAs were performed at the semantic, lexical, morphosyntactic, and phonological levels of language processing. See Table 4 for an overview of the components extracted per language level, and the loadings of the individual variables in the components. At the semantic level, all variables were included in the PCA and clustered into two components. The first semantic component (C1) was primarily defined by the semantic variables related to verbs (i.e., concreteness, imageability and instrumentality), while the second semantic component (C2) was primarily defined by the semantic variables related to nouns (i.e., concreteness, imageability and familiarity). At the lexical level, AoA verbs and frequency nouns were left out of the PCA, because their KMO values were below the acceptable threshold of .50. In the PCA with the remaining variables, two components were constructed. In the first lexical component (C1), TTR nouns, lexical accuracy, AoA nouns, and frequency verbs contributed significantly to score variability, while in the second lexical component (C2), TTR nouns and TTR verbs were the main contributors. At the morphosyntactic level, verb regularity was excluded from the PCA because KMO value that was too low. The remaining variables yielded two components: morphosyntactic C1 was largely defined by grammatical accuracy and finiteness index, while morphosyntactic C2 was characterised mainly by MLU and transitivity. Finally, at the phonological level, all variables were included in the PCA. In the phonological first component (C1), word length nouns and verbs had a significant impact on variability of scores, while phonological errors and cluster index were the main contributors to the second phonological component (C2).

Table 4 *Components and variable loadings extracted from the principal component analysis per level of language processing*

Level of Language Processing	Variable	C1	C2
Semantics	Concreteness verbs	**0.94**[a]	0.20
	Concreteness nouns	0.17	**0.79**
	Imageability verbs	**0.94**	-0.01
	Imageability nouns	0.19	**0.74**
	Familiarity nouns	0.04	**0.84**
	Instrumentality verbs	**-0.58**	-0.40
Lexical	TTR nouns	**0.45**	**0.69**
	TTR verbs	-0.12	**0.90**
	lexical accuracy	**-0.78**	-0.10
	AoA nouns	**0.67**	0.07
	Frequency verbs	**0.80**	0.02
Morphosyntax	MLU	0.28	**0.67**
	Grammatical accuracy	**0.94**	0.12
	Finiteness index	**0.93**	0.23
	Transitivity	0.05	**0.86**
Phonology	Word Length verbs	**0.93**	-0.09
	Word Length nouns	**0.90**	-0.18
	Phonological errors	-0.18	**0.78**
	Cluster Index	-0.03	**0.85**

Note. C1 = Component 1; C2 = Component 2.

[a]Values in **bold** indicate absolute loadings of 0.45 or higher on the component; the corresponding variables were considered the primary contributors to the interpretation of that component.

Group comparisons

Table 5 presents the models for the components extracted from the PCA as well as individual linguistic variables not included in the PCA due to insufficient KMO values, including the covariates age and country and the predictor group. A main effect of group was observed for two components at the morphosyntactic and phonological levels of language. See Figure 2 for graphs displaying the group differences in *z*-scores, after controlling for country and age. At the morphosyntactic level, for

component C1, in which grammatical accuracy and finiteness contributed significantly to score variability, the control group outperformed the patient group (β = -0.68, *SE* = 0.17, *p* < .001). Furthermore, at the phonological level, for component C2, which was strongly influenced by phonemic errors and cluster index, a main effect of group was found (β = -0.48, *SE* = 0.23, *p* = .040), with patients producing more phonemic errors and incorrect consonant clusters. No significant group differences were observed at the lexical level.

For the full statistical models of the exploratory analysis of the effect of tumour type and location and hydrocephalus on language performance, please refer to Appendix C, D and E. No effect of hydrocephalus on preoperative language performance was found. Regarding tumour type, patients with medulloblastomas differed from those with pilocytic astrocytomas by producing nouns of higher frequency (β = 0.14, *SE* = 0.07, *p* = .042). Tumour location showed significant overall effects on the number of utterances, with trend-level effects for the number of words and the first phonological component. The results from the post-hoc analyses can be found in Table 6, and indicate that patients with hemispheric tumours produced fewer words (β = 61.47, *SE* = 22.30, *p* = .040) and utterances (β = 6.65, *SE* = 2.01, *p* = .009) than patients with vermal tumours, suggesting poorer language ability for those with hemispheric tumours.

Table 5 *Linear model per component or separate variable*

Component/variable	age	country[a]		#words	group[b]	adj. R^2
	β (SE, p)	β (SE, p)		β (SE, p)	β (SE, p)	
		United Kingdom	Italy			
Global sample characteristics						
#words	**0.70 (0.12, <.001)**	-10.82 (12.32, .382)	-0.44 (13.46, .974)	—	**-39.42 (10.17, <.001)**	0.28
#utterances	0.02 (0.01, .119)	-2.42 (1.31, .067)	1.30 (1.43, .365)	—	-2.13 (1.08, .051)	0.09
%unclear speech	-0.02 (0.01, .079)	2.26 (1.32, .090)	1.16 (1.44, .423)	—	0.97 (1.09, .375)	0.02
%prompted	**-0.19 (0.06, .001)**	—	8.11 (4.90, .103)	—	**11.37 (4.90, .024)**	0.21
Semantic						
C1: Concr. V+Imageab. V+ Instrum. V	-0.00 (0.00, .421)	**-0.60 (0.08, <.001)**	**1.68 (0.09, <.001)**	—	-0.08 (0.07, .257)	0.87
C2: Concr. N+Imageab. N+ Fam. N	**-0.00 (0.00, .014)**	**1.43 (0.17, <.001)**	**1.38 (0.20, <.001)**	—	0.17 (0.15, .234)	0.42
Lexical						
C1: Lex. acc+AoA N+ Freq. V+TTR N	-0.00 (0.00, .053)	0.03 (0.15, .851)	**-1.68 (0.16, <.001)**	-0.00 (0.00, .820)	0.11 (0.13, .384)	0.59
C2: TTR N+TTR V	**0.01 (0.00, .008)**	0.19 (0.20, .347)	-0.34 (0.21, .119)	**-0.01 (0.00, <.001)**	-0.26 (0.17, .130)	0.29
AoA V	**0.00 (0.00, <.001)**	**-1.13 (0.06, <.001)**	**-0.91 (0.06, <.001)**	—	0.02 (0.05, .717)	0.79
Freq. N	0.00 (0.00, .056)	0.06 (0.05, .210)	0.08 (0.05, .135)	—	-0.02 (0.04, .704)	0.03
Morphosyntax						

C1: Gram. acc.+Finite. Ind.	**0.00 (0.00, .030)**	-0.07 (0.21, .741)	**0.49 (0.23, .032)**	—	**-0.68 (0.17, <.001)**	0.18
C2: MLU+Trans. V	**0.01 (0.00, <.001)**	**0.42 (0.21, .047)**	0.04 (0.23, .845)	—	-0.03 (0.17, .878)	0.16
Regularity V	0.01 (0.02, .593)	**5.58 (2.19, .012)**	**28.69 (2.39, <.001)**	—	0.14 (1.81, .940)	0.59
Phonology						
C1: Length V+Length N	**0.00 (0.00, <.001)**	—	**1.74 (0.11, <.001)**	—	-0.07 (0.11, .514)	0.81
C2: Phon. err.+Clust. ind.	**0.01 (0.00, .005)**	—	-0.37 (0.23, .110)	—	**-0.48 (0.23, .040)**	0.16

Note. C = Component; N = Nouns; V= Verbs; Concr. = Concreteness; Imageab. = Imageability; Instrum. = Instrumentality; Fam. = Familiarity; Lex. acc. = lexical accuracy; AoA = Age of acquisition; Freq. = Frequency; TTR = Type-Token Ratio; Gram. acc. = grammatical accuracy; Finite. ind. = finiteness index; Trans. = Transitivity; Phon. err. = Phonological errors; Clust. ind. = Cluster index; SE = standard error; #words = sample size in number of words; adj. R^2 = Adjusted R^2.

[a]The Netherlands was taken as the reference level

[b]The healthy control group was taken as the reference level

Table 6 *Post-hoc pairwise comparison of tumour locations*

Component/variable	**BS - FV**	**BS - VM**	**BS - CH**	**FV - VM**	**FV - CH**	**VM - CH**
	β (SE, p)	β (SE, p)	β (SE, p)	β (SE, p)	β (SE, p)	β (SE, p)
#words	-4.57 (15.50, .991)	-47.37 (23.40, .193)	14.10 (20.00, .895)	-42.80 (20.70, .178)	18.67 (17.70, .719)	**61.47 (22.30, .040)**
#utterances	1.43 (1.39, .735)	-3.42 (2.10, .375)	3.23 (1.80, .289)	-4.85 (1.86, .057)	1.80 (1.60, .672)	**6.65 (2.01, .009)**
Phon C1: Length Verbs +Length Nouns	-0.15 (0.22, .909)	-0.90 (0.35, .075)	-0.12 (0.33, .982)	-0.75 (0.28, .063)	0.03 (0.28, .999)	0.77 (0.33, .109)

Note. C = Component; #words = sample size in number of words, #utterances = sample size in number of utterances, BS = brainstem; FV = fourth ventricle; VM = vermis; CH = cerebellar hemispheres.

Discussion

The present study investigated preoperative language abilities in children with PFTs using a comprehensive language sample analysis. In contrast to previous research, which has primarily focused on postoperative outcomes [6, 10–12], the current study specifically examined language production before neurosurgical treatment. This approach allowed us to better isolate the effects of the tumour itself from the impact of surgery, radiotherapy and chemotherapy, and postoperative complications such as Posterior Fossa Syndrome. The results show that children with a PFT already present with language abnormalities prior to treatment at the global level, as well as at the morphosyntactic and phonological levels of processing.

At a global level, patients received more examiner prompting during storytelling than typically developing controls. Additionally, they produced shorter narratives in terms of word count, and a similar pattern was observed for the number of utterances, for which the group difference approached statistical significance. The reduced overall productivity and increased need for prompting could be driven by difficulties initiating verbal output, observed in patients after neurosurgical resection [16], but which may to some extent already be present preoperatively. Regarding prompting, it should be noted that examiners collecting the control data were given strong and repeated instructions to refrain from prompting children during the storytelling task. Although clinicians collecting the patient data received the same instructions through the testing manual, this aspect of the procedure may have been less explicitly emphasised in clinical practice. Consequently, clinicians may have provided more support to patients during story retelling.

Regarding the more fine-grained analysis of language processing levels, at the semantic and lexical levels, we did not find differences between patients and controls. This is despite previous research demonstrating postoperative semantic and lexical impairments in patients [17], and research showing that preoperative word-finding errors in children with PFTs were often words semantically related to the target [37]. Moreover, neuroimaging evidence has suggested cerebellar involvement in semantic processing and lexical selection [19–21]. The absence of group differences in the present study may therefore suggest that such semantic and lexical difficulties are not consistently detectable in narrative language before surgery.

At the morphosyntactic level, patients performed worse than controls on the component dominated by grammatical accuracy and finiteness. They produced fewer grammatically correct utterances and omitted or incorrectly inflected finite verbs more often, indicating the presence of morphosyntactic impairments. Difficulties with grammatical processing were also observed by Persson et al. [38], both pre- and postoperatively, in Swedish children treated for PFTs. Regarding the phonological level, patients performed worse than controls on the component dominated by phonological errors and consonant cluster production. The accuracy of consonant cluster production is commonly used to assess phonological development and performance [62–64]. These findings are consistent with those of Bianchi et al. [36], who reported phonological impairments in patients with PFTs preoperatively (NB: they

also refer to these difficulties as apraxia of speech and phonetic disorders, which are motor speech disorders). Notably, no differences were found in word length, suggesting that potential phonological difficulties were not compensated for by an increased use of shorter, phonologically less demanding words, but may instead reflect impairments in phonological encoding and/or the planning and sequencing of speech movements, aligning with Bianchi et al. [36]. Given that children with preoperative dysarthria were included in the study, motor speech impairments may also have contributed to the observed differences in phonological performance.

Taken together, these preoperative differences show that language difficulties are already present before tumour resection. This indicates that impaired language functioning in children with PFTs is not exclusively a consequence of neurosurgical or adjuvant treatment, but may already accompany the presence of the tumour itself. Beyond its relevance for understanding the involvement of the cerebellum in language processing and the origin of language difficulties in this population, this has direct clinical implications. Preoperative difficulties may affect how children express themselves and participate in communication with healthcare professionals during hospitalisation. Awareness of these difficulties is therefore important to ensure that communication is adapted to the individual child's needs and remains accessible throughout clinical care.

The pattern of impairments observed in the present study may also offer insight into how cerebellar lesions affect language. In addition to the involvement of functionally specialised cerebellar language regions, the differences between healthy children and children with PFTs in morphosyntactic and phonological performance may be consistent with accounts proposing a role for the cerebellum in the cognitive timing, planning, and sequencing of speech and language [3]. In particular, the morphosyntactic and phonological stages of language production rely heavily on these processes. After selecting the words (or *lemmas*) for the intended utterance, morphosyntactic encoding involves assigning grammatical features to words and arranging them in the appropriate order during language production [41]. Similarly, during phonological encoding, a speaker must select the phonological forms of *lemmas* and organise phonemes into the appropriate syllabic structures. These phonological representations subsequently guide phonetic encoding, during which articulatory movements are planned and sequenced for speech production. Furthermore, the cerebellum is part of the procedural memory system, which particularly contributes to morphosyntactic processing [65], and is involved in the use of learned motor programmes during speech sound production, as proposed by the DIVA model [66]. Disruption of these cerebellar contributions, potentially through both direct cerebellar dysfunction and altered cerebro-cerebellar communication, may therefore particularly affect morphosyntactic and phonological encoding and subsequent motor speech planning.

Exploratory analyses showed no effect of hydrocephalus and no widespread effect of tumour type on preoperative language performance. However, children with medulloblastomas, a fast-growing, high-grade tumour type, used higher-frequency nouns, which are generally considered easier to retrieve [67, 68], thus suggesting potentially larger difficulties with lexical processing in this group. Additionally, children with hemispheric tumours produced shorter samples in numbers of words and utterances than

children with tumours in the cerebellar vermis, although these findings should be interpreted with caution given the small number of patients in both groups. Reduced verbal output does not necessarily reflect impaired language processing. Motor speech difficulties, for example, may reduce speech productivity and consequently result in shorter narrative samples. However, the location of these tumours also suggests a possible contribution of language processing, as these findings are consistent with evidence for a functional specialisation within the cerebellum, with language-related processing predominantly associated with lateral and posterolateral cerebellar regions, rather than medial or vermal regions [23]. Functional neuroimaging studies in adults further suggest that these regions form part of the language network and contribute selectively to linguistic processing [24]. The reduced verbal output observed in children with hemispheric tumours may therefore reflect direct disruption of cerebellar regions involved in language processing. This interpretation is further supported by the organisation of cerebro-cerebellar connections: the lateral cerebellar hemispheres are more strongly connected to cerebral regions supporting higher-order cognition, including language, whereas the vermis is more strongly linked to brainstem and limbic networks [69–72]. Notably, 8 of 10 hemispheric tumours were right-sided, which is of interest given the predominant involvement of the right cerebellar hemisphere in language processing [23] and its strong connections with language regions in the left cerebral hemisphere [3, 22].

We should note that there were several limitations to this study. The current study focused on group-level differences between children with PFTs and typically developing controls. Although this approach is useful for identifying general patterns of preoperative language difficulties, it does not fully capture the individual variability that may exist between patients. Children with PFTs may differ substantially, for instance in tumour location, tumour growth rate, hydrocephalus, dysarthria and oculomotor difficulties, all of which are ignored when analyses are restricted to group averages. Future studies could complement group-level analyses with case-to-control-group comparisons, as performed by Svaldi et al. [17], to determine whether individual patients show selective impairments relative to a matched control group. However, the fact that some impairments emerge in group comparisons despite large individual variability adds evidence of potential generalisable impairments in these patients, which is useful to argue for the need of carrying out clinical assessments for language screening in this patient population.

A further limitation concerns the selection of patients and controls. Patients with documented neuropsychological, speech or language impairments were excluded, as we could not reliably determine whether these difficulties were related to the tumour or to an independent developmental disorder. Although this approach reduced the risk of attributing pre-existing developmental difficulties to the tumour, it may also have resulted in the exclusion of children whose difficulties were already early signs of tumour growth. As a result, the extent of preoperative language impairments may have been underestimated. Future research could investigate the onset and progression of language difficulties prior to diagnosis to explore their potential value as early indicators of PFTs. Additionally, patients were tested in hospital shortly before surgery and may have been affected by fatigue, stress, or medication, which did not apply to the control group and may therefore have contributed to group differences. Moreover, Dutch and Italian controls were screened for general cognitive and language abilities to determine whether they could be included as typically developing control participants. These

background assessments were not available for patients. We therefore cannot exclude the possibility that differences in these abilities contributed to the observed group differences.

Another limitation concerns the type of task used to collect a language sample. As also described in Reinders et al. [39], the picture-based narrative task used in this study may have been less sensitive to subtle language differences than more naturalistic or conversational elicitation methods. This may be relevant when interpreting the absence of semantic and lexical group differences. In a picture-based narrative, the content of the story is largely constrained by the depicted events, thereby limiting the range of concepts and words that children are likely to produce. In addition, picture stimuli may be less sensitive to semantic differences because they induce a bias towards the use of highly imageable and concrete language [17]. As a result, differences in semantic or lexical processing may have been less apparent in the present task. Furthermore, multilingualism could not be considered in the current study, as information on multilingualism was not available for the English control participants in the Open Science Framework from which they were retrieved [50]. Finally, the current analyses explored the effects of tumour type, hydrocephalus and tumour location. Although some effects were observed for tumour type and location, these analyses would benefit substantially from a larger sample size, which would allow for more robust comparisons across tumour types and locations. For instance, larger samples could help differentiate between the gradual impact of slow-growing tumours on the brain and the more acute effects of fast-growing tumours, which may leave less opportunity for neuroplastic reorganisation. A larger sample size would also enable a finer-grained analysis of tumour location beyond the four location categories used in the current study. This could help identify which cerebellar and brainstem regions are most strongly associated with language difficulties and how disruption of these regions and their connections may affect language processing. Ultimately, this may contribute to a more complete understanding of the role of the cerebellum and related structures in language processing.

Conclusion

In this study, we used a psycholinguistic language sample analysis to compare preoperative language production in children with PFTs to that of typically developing peers. We observed morphosyntactic and phonological difficulties in children with PFTs already before treatment came into play. These findings indicate that language difficulties in this population cannot solely be attributed to treatment-related factors such as surgery, chemotherapy, or radiotherapy, but may already emerge as a consequence of tumour-related cerebellar and brainstem dysfunction. These findings are consistent with growing evidence that the cerebellum and its connections make a functionally relevant contribution to the language network and language processing. The anatomical substrates and mechanisms underlying these impairments, including the role of tumour location, should be further studied.

The observed preoperative language difficulties highlight the importance of assessing language abilities before neurosurgical treatment. Early identification of language difficulties may facilitate timely clinical monitoring and intervention and establish a baseline against which postoperative changes can be

evaluated. Importantly, awareness of pre-existing communication difficulties may also allow clinicians to provide appropriate communication support during the hospital stay.

Declarations

Funding

This publication is supported by funding awarded to the project Verb Processing and Verb Learning in Children With Paediatric Posterior Fossa Tumours (with file number VI.Vidi.201.003) of the research programme NWO-Talentprogramma Vidi SGW 2020 financed by the Dutch Research Council (NWO). Jonathan Kjær Grønbæk and Ditte Boeg Thomsen received funding from the Inge Lehmann grant (grant number 10.46540/4302-00027B) from the Independent Research Fund Denmark. Karin Persson received funding from The Swedish Childhood Cancer Foundation, Queen Silvia's Jubilee Fund, Jonas Foundation.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Ethical considerations

The current study used patient data from the European CMS Study. Data collection for this project was approved by the Research Ethics Committees of the Capital Region in Denmark (H-6-2014-002). The first participation of Dutch centres was approved by the Medical Ethics Review Committee (CMO) of Radboud University Medical Center, Nijmegen (NL55516.091.15). Following a temporary discontinuation, the second participation of Dutch centres received ethical approval from the Medical Ethics Review Committee NedMec (METC NedMec; NL81967.041.22). Participation of centres in the UK was approved by the North West - Liverpool East Research Ethics Committee (16/NW/0633). Participation of the Italian centre was approved by the Ethical Committee of the IRCCS Bambino Gesù Children's Hospital (1923/2019). All procedures were conducted in accordance with the Declaration of Helsinki.

Human ethics and consent to participate

Written informed consent was obtained from all individual patients and controls or from a parent of the participating children.

Data availability

The paper reports a secondary analysis of data from the European CMS study. Requests for access to and reuse of the data should be directed to the principal investigator of the European CMS study, René Mathiasen (Rene.Mathiasen@regionh.dk).

Author contributions

Conceptualisation: Aliene Reinders and Vânia de Aguiar; **Methodology:** Aliene Reinders, Vânia de Aguiar and Cheyenne Svaldi; **Project administration and resources:** Jonathan Kjær Grønbæk, René Mathiasen, Christine Dahl, Marianne Juhler, Barry Pizer, Colin Thorbinson, Kristian Aquilina, Eelco Hoving, Andrea Carai, Angela Mastronuzzi and Vânia de Aguiar; **Investigation:** Aliene Reinders, Cheyenne Svaldi, Bianca Andreozzi, Kim Vos and Elisa Gottardi; **Data curation and formal analysis:** Aliene Reinders and Cheyenne Svaldi; **Supervision:** Vânia de Aguiar and Roel Jonkers; **Writing - original draft preparation:** Aliene Reinders; **Writing - review and editing:** all authors reviewed the manuscript; **Funding acquisition:** Vânia de Aguiar, Ditte Boeg Thomsen, Marianne Juhler and Jonathan Kjær Grønbæk

Acknowledgements

We thank the CMS study team for their sustained efforts in patient recruitment and longitudinal follow-up, and the patients whose time and participation made this research possible. We also thank all control participants and their parents for their willingness to participate in the study.

References

1. Dörner L, Fritsch MJ, Stark AM, Mehdorn HM. Posterior fossa tumors in children: how long does it take to establish the diagnosis? Childs Nerv Syst. 2007;23:887–90. https://doi.org/10.1007/s00381-007-0323-8
2. Rickert CH, Paulus W. Epidemiology of central nervous system tumors in childhood and adolescence based on the new WHO classification. Childs Nerv Syst ChNS Off J Int Soc Pediatr Neurosurg. 2001;17:503–11. https://doi.org/10.1007/s003810100496
3. Marien P, Engelborghs S, Fabbro F, De Deyn PP. The Lateralized Linguistic Cerebellum: A Review and a New Hypothesis. Brain Lang. 2001;79:580–600. https://doi.org/10.1006/brln.2001.2569
4. Brandão LA, Young Poussaint T. Posterior Fossa Tumors. Neuroimaging Clin N Am. 2017;27:1–37. https://doi.org/10.1016/j.nic.2016.08.001
5. Muzumdar D, Ventureyra EC. Treatment of posterior fossa tumors in children. Expert Rev Neurother. Taylor & Francis; 2010;10:525–46. https://doi.org/10.1586/ern.10.28
6. Catsman-Berrevoets CE, Aarsen FK. The spectrum of neurobehavioural deficits in the Posterior Fossa Syndrome in children after cerebellar tumour surgery. Cortex. 2010;46:933–46. https://doi.org/10.1016/j.cortex.2009.10.007
7. Khan RB, Patay Z, Klimo P, Huang J, Kumar R, Boop FA, et al. Clinical features, neurologic recovery, and risk factors of postoperative posterior fossa syndrome and delayed recovery: a prospective study. Neuro-Oncol. 2021;23:1586–96. https://doi.org/10.1093/neuonc/noab030
8. Grønbæk JK, Wibroe M, Toescu S, Frič R, Thomsen BL, Møller LN, et al. Postoperative speech impairment and surgical approach to posterior fossa tumours in children: a prospective European multicentre cohort study. Lancet Child Adolesc Health. 2021;5:814–24. https://doi.org/10.1016/S2352-4642(21)00274-1

9. Gudrunardottir T, Morgan AT, Lux AL, Walker DA, Walsh KS, Wells EM, et al. Consensus paper on post-operative pediatric cerebellar mutism syndrome: the Iceland Delphi results. Childs Nerv Syst. 2016;32:1195–203. https://doi.org/10.1007/s00381-016-3093-3
10. Lassaletta A, Bouffet E, Mabbott D, Kulkarni AV. Functional and neuropsychological late outcomes in posterior fossa tumors in children. Childs Nerv Syst. 2015;31:1877–90. https://doi.org/10.1007/s00381-015-2829-9
11. Lewis FM, Murdoch BE. Language Outcomes Following Risk-Adapted Treatments for Tumors Located Within the Posterior Fossa. J Child Neurol. SAGE Publications Inc; 2011;26:440–52. https://doi.org/10.1177/0883073810382659
12. Riva D, Giorgi C. The cerebellum contributes to higher functions during development: Evidence from a series of children surgically treated for posterior fossa tumours. Brain. 2000;123:1051–61. https://doi.org/10.1093/brain/123.5.1051
13. Murdoch BE, Docking KM, Ward EC. Language and Phonological Awareness Abilities of Children treated for Posterior Fossa Tumor. Neurogenic Lang Disord Child [Internet]. Brill; 2004 [cited 2026 Jan 21]. p. 87–126. https://doi.org/10.1163/9780080473574_008
14. Mabbott DJ, Penkman L, Witol A, Strother D, Bouffet E. Core neurocognitive functions in children treated for posterior fossa tumors. Neuropsychology. American Psychological Association; 2008;22:159–68. https://doi.org/10.1037/0894-4105.22.2.159
15. Hudson LJ, Murdoch BE. Spontaneously generated narratives of children treated for posterior fossa tumour. Aphasiology. Routledge; 1992;6:549–66. https://doi.org/10.1080/02687039208249491
16. De Smet HJ, Baillieux H, Wackenier P, De Praeter M, Engelborghs S, Paquier PF, et al. Long-term cognitive deficits following posterior fossa tumor resection: A neuropsychological and functional neuroimaging follow-up study. Neuropsychology. 2009;23:694–704. https://doi.org/10.1037/a0016106
17. Svaldi C, Paquier P, Keulen S, van Elp H, Catsman-Berrevoets C, Kingma A, et al. Characterising the Long-Term Language Impairments of Children Following Cerebellar Tumour Surgery by Extracting Psycholinguistic Properties from Spontaneous Language. The Cerebellum. 2024;23:523–44. https://doi.org/10.1007/s12311-023-01563-z
18. Jobson KR, Hoffman LJ, Metoki A, Popal H, Dick AS, Reilly J, et al. Language and the Cerebellum: Structural Connectivity to the Eloquent Brain. Neurobiol Lang. 2024;5:652–75. https://doi.org/10.1162/nol_a_00085
19. D'Mello AM, Turkeltaub PE, Stoodley CJ. Cerebellar tDCS Modulates Neural Circuits during Semantic Prediction: A Combined tDCS-fMRI Study. J Neurosci. Society for Neuroscience; 2017;37:1604–13. https://doi.org/10.1523/JNEUROSCI.2818-16.2017
20. Mariën P, van Dun K, Van Dormael J, Vandenborre D, Keulen S, Manto M, et al. Cerebellar induced differential polyglot aphasia: A neurolinguistic and fMRI study. Brain Lang. 2017;175:18–28. https://doi.org/10.1016/j.bandl.2017.09.001

21. Lesage E, Nailer EL, Miall RC. Cerebellar BOLD signal during the acquisition of a new lexicon predicts its early consolidation. Brain Lang. 2016;161:33–44. https://doi.org/10.1016/j.bandl.2015.07.005
22. Lesage E, Hansen PC, Miall RC. Right Lateral Cerebellum Represents Linguistic Predictability. J Neurosci. Society for Neuroscience; 2017;37:6231–41. https://doi.org/10.1523/JNEUROSCI.3203-16.2017
23. de Aguiar V, Reinders A, Svaldi C. Speech and Language in Posterior Fossa Syndrome. In: Nesi H, Milin P, editors. Int Encycl Lang Linguist Third Ed [Internet]. London: Elsevier; 2026 [cited 2026 Sept 3]. p. 445–52. https://doi.org/10.1016/B978-0-323-95504-1.01236-9
24. Casto C, Poliak M, Tuckute G, Small H, Sherlock P, Wolna A, et al. The cerebellar components of the human language network. Neuron. 2026;114:1504-1523.e11. https://doi.org/10.1016/j.neuron.2025.12.030
25. Lewis FM, Murdoch BE. Differential language trajectories following treatment for pediatric posterior fossa tumor: An investigation of four cases. NeuroRehabilitation. SAGE Publications; 2013;32:165–83. https://doi.org/10.3233/NRE-130834
26. Fabbro F, Moretti R, Bava A. Language impairments in patients with cerebellar lesions. J Neurolinguistics. 2000;13:173–88. https://doi.org/10.1016/S0911-6044(00)00010-5
27. Vlasova RM, Panikratova YR, Pechenkova EV. Systematic Review and Meta-analysis of Language Symptoms due to Cerebellar Injury. The Cerebellum. 2023;22:1274–86. https://doi.org/10.1007/s12311-022-01482-5
28. Satoer D, Koudstaal PJ, Visch-Brink E, van der Giessen RS. Cerebellar-Induced Aphasia After Stroke: Evidence for the “Linguistic Cerebellum.” The Cerebellum. 2024;23:1457–65. https://doi.org/10.1007/s12311-024-01658-1
29. Schmahmann JD, Pandya DN. The Cerebrocerebellar System. In: Schmahmann JD, editor. Rev Of [Internet]. Academic Press; 1997 [cited 2026 Oct 19]. p. 31–60. https://doi.org/10.1016/S0074-7742(08)60346-3
30. Garrard P, Bradshaw D, Jager H, Thompson A, Losseff N, Playford D. Cognitive dysfunction after isolated brain stem insult. An underdiagnosed cause of long term morbidity. J Neurol Neurosurg Psychiatry. 2002;73:191–4. https://doi.org/10.1136/jnnp.73.2.191
31. Hoffmann M, Watts A. Cognitive dysfunction in isolated brainstem stroke: A neuropsychological and SPECT study. J Stroke Cerebrovasc Dis. Elsevier; 1998;7:24–31. https://doi.org/10.1016/S1052-3057(98)80018-9
32. Hatakeyama M, Watanabe M, Koide S, Hashida H, Taneda T, Akiyama N, et al. Clinical and Radiological Features of Aphasia Caused by Brainstem Infarction: Two Case Reports. Cerebellum Lond Engl. 2026;25:27. https://doi.org/10.1007/s12311-026-01974-8
33. Svaldi C, Ntemou E, Jonkers R, Kohnen S, de Aguiar V. Language outcomes in children who underwent surgery for the removal of a posterior fossa tumor: A systematic review. Eur J Paediatr Neurol. 2024;48:129–41. https://doi.org/10.1016/j.ejpn.2023.12.005

34. Catelan S, Santini B, Sala F, Feletti A. Cerebellar mutism syndrome: the importance of preoperative language assessment. Childs Nerv Syst. 2022;38:1993–7. https://doi.org/10.1007/s00381-022-05497-5
35. Di Rocco C, Chieffo D, Frassanito P, Caldarelli M, Massimi L, Tamburrini G. Heralding Cerebellar Mutism: Evidence for Pre-surgical Language Impairment as Primary Risk Factor in Posterior Fossa Surgery. The Cerebellum. 2011;10:551–62. https://doi.org/10.1007/s12311-011-0273-2
36. Bianchi F, Chieffo DPR, Frassanito P, Di Rocco C, Tamburrini G. Cerebellar mutism: the predictive role of preoperative language evaluation. Childs Nerv Syst. 2020;36:1153–7. https://doi.org/10.1007/s00381-019-04252-7
37. Persson K, Boeg Thomsen D, Fyrberg Å, Castor C, Aasved Hjort M, Andreozzi B, et al. Preoperative word-finding difficulties in children with posterior fossa tumours: a European cross-sectional study. Childs Nerv Syst. 2024;40:87–97. https://doi.org/10.1007/s00381-023-06119-4
38. Persson K, Boeg Thomsen D, Andersson K, Tiberg I, Castor C, Grønbæk J, et al. Narrative Ability in Swedish Children Treated for Posterior Fossa Tumours: Macro- and Microstructural Performance Before and 1–4 Weeks After Surgery. Int J Lang Commun Disord. 2026;61:e70248. https://doi.org/10.1111/1460-6984.70248
39. Reinders A, Svaldi C, Kingma A, Grønbæk JK, Thomsen DB, Persson K, et al. Analysis of Presurgical Language in Children with Posterior Fossa Tumours Relative to Postoperative Speech Outcomes: Findings from the European CMS Study. The Cerebellum. 2026;25:48. https://doi.org/10.1007/s12311-026-01987-3
40. Docking K, Munro N, Marshall T, Togher L. Narrative skills of children treated for brain tumours: The impact of tumour and treatment related variables on microstructure and macrostructure. Brain Inj. 2016;30:1005–18. https://doi.org/10.3109/02699052.2016.1147602
41. Levelt WJM. Speaking: From Intention to Articulation [Internet]. The MIT Press; 1989 [cited 2026 May 18]. https://doi.org/10.7551/mitpress/6393.001.0001
42. Hymes D. Models of the Interaction of Language and Social Life. In: Gumperz JJ, Hymes D, editors. Dir Socioling Ethnogr Commun. New York: Holt, Rinehart and Winston; 1972. p. 35–71.
43. Shallice T. Specialisation within the semantic system. Cogn Neuropsychol. Routledge; 1988;5:133–42. https://doi.org/10.1080/02643298808252929
44. Chéileachair FN, Chondrogianni V, Sorace A, Paradis J, Aguiar VD. Developmental language disorder in sequential bilinguals: Characterising word properties in spontaneous speech. J Child Lang. 2023;50:954–80. https://doi.org/10.1017/S0305000922000241
45. Marcotte K, Graham NL, Fraser KC, Meltzer JA, Tang-Wai DF, Chow TW, et al. White Matter Disruption and Connected Speech in Non-Fluent and Semantic Variants of Primary Progressive Aphasia. Dement Geriatr Cogn Disord EXTRA. 2017;7:52–73. https://doi.org/10.1159/000456710
46. Bird H, Lambon Ralph MA, Patterson K, Hodges JR. The rise and fall of frequency and imageability: noun and verb production in semantic dementia. Brain Lang. 2000;73:17–49. https://doi.org/10.1006/brln.2000.2293

47. Fraser KC, Meltzer JA, Graham NL, Leonard C, Hirst G, Black SE, et al. Automated classification of primary progressive aphasia subtypes from narrative speech transcripts. Cortex. 2014;55:43–60. https://doi.org/10.1016/j.cortex.2012.12.006
48. Wibroe M, Cappelen J, Castor C, Clausen N, Grillner P, Gudrunardottir T, et al. Cerebellar mutism syndrome in children with brain tumours of the posterior fossa. BMC Cancer. 2017;17:439. https://doi.org/10.1186/s12885-017-3416-0
49. Bishop DVM. ERRNI: Expression, Reception and Recall of Narrative Instrument. London: Harcourt Assessment; 2004.
50. Frizelle P, Thompson PA, Bishop D. Excel data. OSF; 2024 [cited 2025 Feb 11]; https://osf.io/t6afa/. Accessed 11 Feb 2025
51. Wechsler D. WPPSI-IV (Wechsler Preschool and Primary Scale of Intelligence - Fourth Edition). Firenze, Italy: Giunti Psychometrics; 2019.
52. Davis JL, Matthews RN. NEPSY-II Review: Korkman, M., Kirk, U., & Kemp, S. (2007). NEPSY—Second Edition (NEPSY-II). San Antonio, TX: Harcourt Assessment. J Psychoeduc Assess. SAGE Publications Inc; 2010;28:175–82. https://doi.org/10.1177/0734282909346716
53. Raven J. Raven Progressive Matrices. In: McCallum RS, editor. Handb Nonverbal Assess. Kluwer Academic/Plenum Publishers; 2003. p. 223–37.
54. Wechsler D, Naglieri JA. Wechsler Nonverbal Scale of Ability. San Antonio, TX: Harcourt Assessment; 2006.
55. Wiig EH, Semel E, Secord WA. CELF Preschool-2-NL: Clinical Evaluation of Language Fundamentals Preschool – Second Edition. Pearson Benelux B.V.; 2012.
56. Wiig EH, Semel E, Secord WA. CELF-5-NL: Clinical Evaluation of Language Fundamentals – Fifth Edition. Pearson Benelux B.V.; 2019.
57. Wittenburg P, Brugman H, Russel A, Klassmann A, Sloetjes H. ELAN : a professional framework for multimodality research. 2006 [cited 2025 Jan 30]. p. 1556–9. https://pure.mpg.de/pubman/faces/ViewItemOverviewPage.jsp?itemId=item_60436. Accessed 30 Jan 2025
58. Verbeek J, van den Dungen L, Bakker A. Spontane Taal Analyse Procedure. Verantwoording van het STAP-instrument, ontwikkeld door Margreet van Ierland. Universiteit van Amsterdam; 2008.
59. Fox J. Applied Regression Analysis and Generalized Linear Models. SAGE Publications; 2015.
60. Hess CW, Sefton KM, Landry RG. Sample Size and Type-Token Ratios for Oral Language of Preschool Children. J Speech Lang Hear Res. American Speech-Language-Hearing Association; 1986;29:129–34. https://doi.org/10.1044/jshr.2901.129
61. Posit Team. RStudio: Integrated Development Environment for R [Internet]. Boston, MA; 2025 [cited 2025 Jan 30]. http://www.posit.co/. Accessed 30 Jan 2025
62. Kehoe M, Niederberger N, Bouchut A-L. The development of a speech sound screening test for European French-speaking monolingual and bilingual children. Int J Speech Lang Pathol. Taylor &

Francis; 2021;23:135–44. https://doi.org/10.1080/17549507.2020.1750699

63. McLeod S, Doorn J, Reed VA. Realizations of consonant clusters by children with phonological impairment. Clin Linguist Phon. 1997;11:85–113. https://doi.org/10.1080/02699209708985185
64. Scheffer A, Keij B, Hakvoort B, Ottow-Henning E, Gerrits E, Wijnen F. Speech sound development of young Dutch children with a developmental language disorder: A complex matter. Int J Lang Commun Disord. 2024;59:2706–22. https://doi.org/10.1111/1460-6984.13109
65. Ullman MT. Contributions of memory circuits to language: the declarative/procedural model. Cognition. 2004;92:231–70. https://doi.org/10.1016/j.cognition.2003.10.008
66. Tourville JA, Guenther FH. The DIVA model: A neural theory of speech acquisition and production. Lang Cogn Process. Routledge; 2011;26:952–81. https://doi.org/10.1080/01690960903498424
67. Nozari N, Kittredge AK, Dell GS, Schwartz MF. Naming and repetition in aphasia: Steps, routes, and frequency effects. J Mem Lang. 2010;63:541–59. https://doi.org/10.1016/j.jml.2010.08.001
68. Alario F-X, Ferrand L, Laganaro M, New B, Frauenfelder UH, Segui J. Predictors of picture naming speed. Behav Res Methods Instrum Comput. 2004;36:140–55. https://doi.org/10.3758/BF03195559
69. Schmahmann JD. From movement to thought: Anatomic substrates of the cerebellar contribution to cognitive processing. Hum Brain Mapp. 1996;4:174–98. https://doi.org/10.1002/(SICI)1097-0193(1996)4:3%3C174::AID-HBM3%3E3.0.CO;2-0
70. Schmahmann JD, Sherman JC. The cerebellar cognitive affective syndrome. Brain. 1998;121:561–79. https://doi.org/10.1093/brain/121.4.561
71. Stoodley CJ, Schmahmann JD. Functional topography in the human cerebellum: A meta-analysis of neuroimaging studies. NeuroImage. 2009;44:489–501. https://doi.org/10.1016/j.neuroimage.2008.08.039
72. Buckner RL. The Cerebellum and Cognitive Function: 25 Years of Insight from Anatomy and Neuroimaging. Neuron. Elsevier; 2013;80:807–15. https://doi.org/10.1016/j.neuron.2013.10.044
73. Brysbaert M, Warriner AB, Kuperman V. Concreteness ratings for 40 thousand generally known English word lemmas. Behav Res Methods. 2014;46:904–11. https://doi.org/10.3758/s13428-013-0403-5
74. Brysbaert M, Stevens M, De Deyne S, Voorspoels W, Storms G. Norms of age of acquisition and concreteness for 30,000 Dutch words. Acta Psychol (Amst). 2014;150:80–4. https://doi.org/10.1016/j.actpsy.2014.04.010
75. Montefinese M, Ambrosini E, Fairfield B, Mammarella N. The adaptation of the Affective Norms for English Words (ANEW) for Italian. Behav Res Methods. 2014;46:887–903. https://doi.org/10.3758/s13428-013-0405-3
76. Scott GG, Keitel A, Becirspahic M, Yao B, Sereno SC. The Glasgow Norms: Ratings of 5,500 words on nine scales. Behav Res Methods. 2019;51:1258–70. https://doi.org/10.3758/s13428-018-1099-3
77. Van Loon-Vervoorn WA. Afbeeldbaarheidsnormen van 1087 Nederlandse woorden. [Imageability norms for 1,087 Dutch words.]. Ned Tijdschr Psychol. Netherlands: Bohn Stafleu Van Loghum:

Springer; 1984;39:462–70.
78. Hermans D, De Houwer J. Affective and subjective familiarity ratings of 740 Dutch words. Psychol Belg. Belgium: Belgian Association for Psychological Science; 1994;34:115–39.
79. Kuperman V, Stadthagen-Gonzalez H, Brysbaert M. Age-of-acquisition ratings for 30,000 English words. Behav Res Methods. 2012;44:978–90. https://doi.org/10.3758/s13428-012-0210-4
80. Montefinese M, Vinson D, Vigliocco G, Ambrosini E. Italian Age of Acquisition Norms for a Large Set of Words (ItAoA). Front Psychol [Internet]. Frontiers; 2019 [cited 2025 June 3];10. https://doi.org/10.3389/fpsyg.2019.00278
81. van Heuven WJB, Mandera P, Keuleers E, Brysbaert M. Subtlex-UK: A New and Improved Word Frequency Database for British English. Q J Exp Psychol. SAGE Publications; 2014;67:1176–90. https://doi.org/10.1080/17470218.2013.850521
82. Keuleers E, Brysbaert M, New B. SUBTLEX-NL: A new measure for Dutch word frequency based on film subtitles. Behav Res Methods. 2010;42:643–50. https://doi.org/10.3758/BRM.42.3.643
83. Marian V, Bartolotti J, Chabal S, Shook A. CLEARPOND: Cross-Linguistic Easy-Access Resource for Phonological and Orthographic Neighborhood Densities. PLOS ONE. Public Library of Science; 2012;7:e43230. https://doi.org/10.1371/journal.pone.0043230

Figures

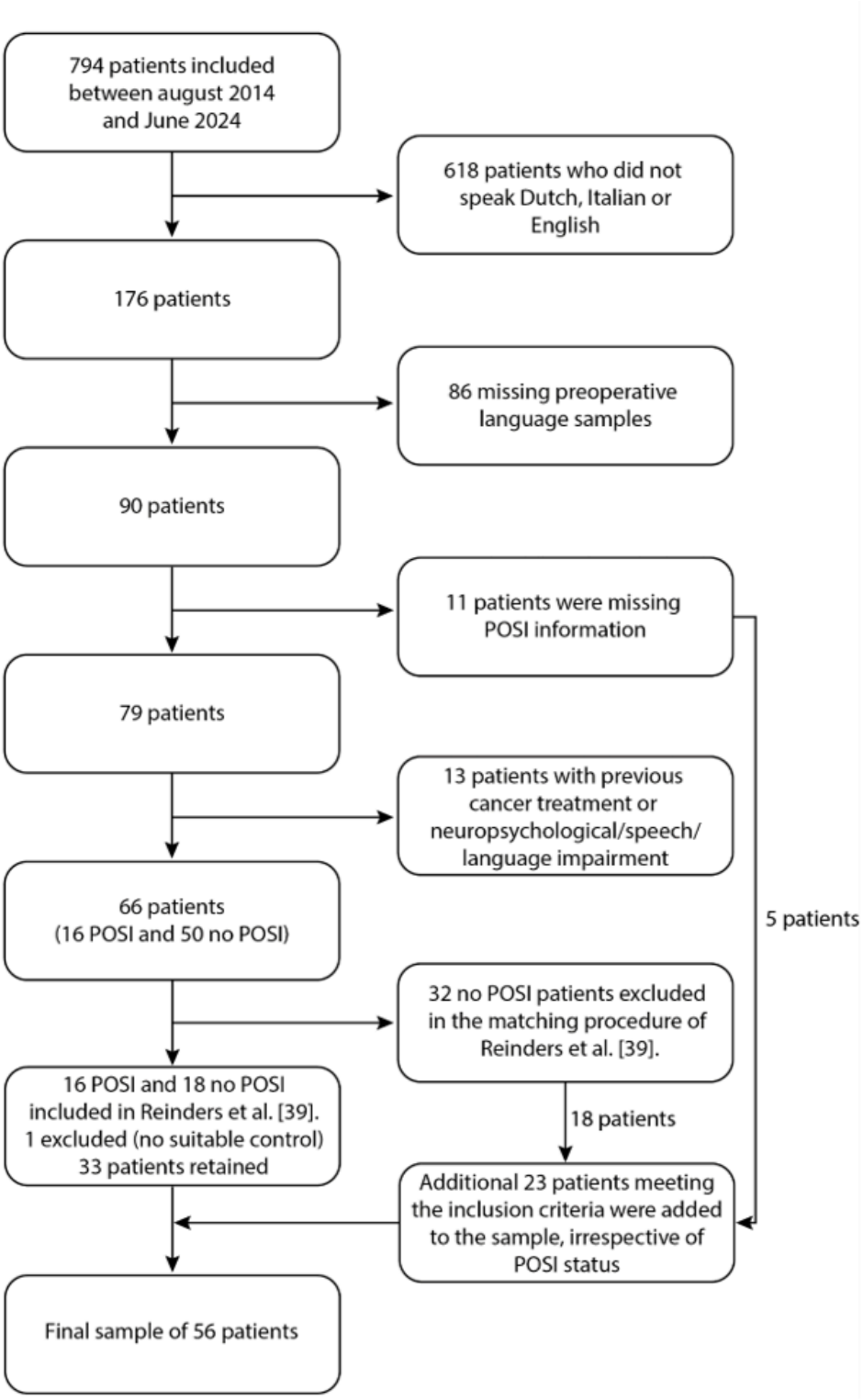


Figure 1

Process of participant inclusion

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.docx