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Language outcomes in children who underwent surgery for the removal of a posterior fossa tumor: A systematic review

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ABSTRACT

Background: Children who underwent posterior fossa tumor removal may have spoken or written language impairments. The present systematic review synthesized the literature regarding the language outcomes in this population. Benefits of this work were the identification of shortcomings in the literature and a starting point toward formulating guidelines for postoperative language assessment.
Methods: A systematic literature search was conducted, identifying studies with patients who had posterior fossa surgery before 18 years of age. Included studies were narratively synthesized to understand language outcomes by language function (e.g., phonology, morphosyntax) at a group and individual level. Furthermore, the influence of several mediators (e.g., postoperative cerebellar mutism syndrome (pCMS), tumor type) was investigated. A critical evaluation of the language assessment tools was conducted.
Results: The narrative synthesis of 66 studies showed that a broad spectrum of language impairments has been described, characterized by a large interindividual heterogeneity. Patients younger at diagnosis, receiving treatment for a high-grade tumor and/or radiotherapy and diagnosed with pCMS seemed more prone to impairment. Several gaps in language assessment remain, such as a baseline preoperative assessment and the assessment of pragmatics and morphosyntax. Further, there were important methodological differences in existing studies which complicated our ability to accurately guide clinical practice.
Conclusion: Children who had posterior fossa surgery seem to be at risk for postoperative language impairment. These results stress the need for language follow-up in posterior fossa tumor survivors.

1. Introduction

Posterior fossa tumors are the most common pediatric brain tumors [1,2]. These tumors are generally surgically resected, but, depending on tumor malignancy and the extent of surgical resection, additional treatments may include adjuvant chemo- and or radiotherapy [3]. Following surgical resection, children with posterior fossa tumors can demonstrate cognitive (e.g., attention deficits), behavioral-affective (e.g., apathy) and speech and/or language sequelae (e.g., dysarthria, agrammatism) [4–6]. When accompanied by cerebellar mutism (i.e., a transient significant reduction or complete absence of speech), this cluster of impairments is referred to as postoperative cerebellar mutism syndrome (pCMS) [7]. Language deficits may, however, also occur without being preceded by pCMS [4]. Treatment advances have improved the five-year survival prognosis of children with posterior fossa tumors [8,9]. Consequently, the behavioral impairments and the need for adapted rehabilitation have started to receive more attention [10].

Language can be affected in posterior fossa tumor survivors.

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Abbreviations

pCMS	postoperative cerebellar mutism syndrome
PRISMA	Preferred Reporting Items for Systematic Review and Meta-Analysis
SPIDER	Sample, Phenomenon of Interest, Design, Evaluation, Research
GRADE	Grades of Recommendation, Assessment, Development and Evaluation
SWiM	synthesis without meta-analysis

However, it is still unclear if some language functions are more prone to impairment than others and a considerable variation in the presentation and severity of language deficits has been observed [11]. Several risk factors or mediators have been proposed to explain this clinical heterogeneity, including characteristics of the patient (e.g., age at diagnosis), the tumor (e.g., tumor histology), the treatment approach (e.g., extent of tumor resection), and treatment-related complications (e.g., hydrocephalus) [12,13]. In general, the influence of mediators on postoperative language outcomes is still under much debate. Another possible explanation for the inconsistency in language outcomes might be the variety and sensitivity of the assessment tools administered.

To the best of our knowledge, no previous study has specifically considered the literature on language outcomes in children with posterior fossa tumors [14–16]. However, previous systematic reviews have studied related questions, including language deficits, but within a broader range of neuropsychological outcomes [15] or for children with different kinds of brain tumors [14] or different types of cerebellar injury [16]. Hence, these systematic reviews did not provide an in-depth evaluation of the impaired language functions or the influence of mediators. Also, the language assessment tools used in the literature were not described.

Several narrative reviews focused on speech or language. Reviews by Gelabert-González and Fernández-Villa [17] and Lanier and Abrams [18], for example, focused on postoperative speech impairments, while the present review will focus on language. Other reviews addressed the language outcomes in children who had posterior fossa surgery within a broader topic, such as the cerebellar involvement in neurocognition [19] and language [20] across different clinical and non-clinical populations. Hence, previous studies included research on language outcomes related to several etiologies, while the current review focuses specifically on children with posterior fossa tumors. Other reviews reported on language impairments, while we will describe both strengths and weaknesses in the language profiles [21].

1.1. The present systematic review

This systematic review primarily aimed to synthesize the literature on the language outcomes of children, adolescents and adults who had posterior fossa tumor surgery during childhood. It set out to identify which language levels are prone to impairment and which tend to be preserved. Secondary research questions addressed the role of possible mediators of these language outcomes. Also, the language assessment tools used in these studies were described in detail. A complete appraisal of existing research allowed us to identify gaps in language research and hence suggest research directions for future studies and possible implications for clinical practice.

This study was guided by the following research questions:

(1) What are the language outcomes of children, adolescents and adults who had posterior fossa tumor surgery during childhood at a group and individual level?

More specifically, the language outcomes on a lexical-semantic, phonological, morphosyntactic, and pragmatic level and for literacy and verbal learning were investigated, as reflected by measures tapping into those aspects of language.

(2) Do the observed language impairments differ depending on:
   a. the emergence and duration of pCMS?
   b. patient characteristics, tumor characteristics and characteristics of tumor treatment?
(3) Which tools have been used for the assessment of the language outcomes?

2. Methodology

The systematic review methodology followed the Preferred Reporting Items for Systematic Review and Meta-Analysis guidelines (PRISMA) [22]. A protocol was pre-registered on PROSPERO (registration number CRD42021236513) and can be found on Open Science Framework [23] (https://osf.io/5j6by/). Deviations from the original protocol are listed in Appendix A.

2.1. Eligibility criteria

Eligibility criteria were determined using the Sample, Phenomenon of Interest, Design, Evaluation, Research type tool (SPIDER) [24]. To be included, studies had to report patients who (1) had posterior fossa tumor surgery before 18 years of age; (2) did not have a premorbid history of developmental language, learning or neuropsychiatric impairment; (3) did not have a reported preoperative language impairment caused by tumor presence; and (4) were at least two years of age at language assessment. Both mono- and multilingual participants were included. Language had to be assessed using a standardized or researcher-developed test, or a spontaneous language analysis compared to appropriate norms or a control group. Studies in languages other than English were included if one of the authors was proficient in that language (i.e., Spanish, German or Dutch).

2.2. Information sources

A broad search strategy was applied. Potentially eligible peer-reviewed and grey literature was collected through searches of multiple electronic databases (see protocol), including all years up until the time the literature search was conducted (February 2021). Authors of the included articles were contacted for unpublished articles and inaccessible papers. The 'cited by' function in Google Scholar was used to search for forward citations. Finally, the reference lists of review studies were hand-searched for missed articles.

2.3. Search strategy

Relevant search terms for the population (e.g., 'posterior fossa tumor'), intervention (e.g., 'posterior fossa surgery') and outcomes (e.g., 'vocabulary') were identified based on previous systematic reviews and during consultations with a research librarian. These terms were evaluated during trial searches. The search string for PubMed can be found in Appendix B. The search strings for the other electronic interfaces can be found in the systematic review protocol [23] (https://osf.io/5j6by/).

2.4. Study selection

After deduplication, the titles and abstracts and full text of the retrieved articles were independently assessed for eligibility by two authors (Cheyenne Svaldi and Effy Ntemou). If a study was in a language other than English, two authors proficient in that language acted as reviewers. Study selection was facilitated by signaling questions (see protocol). In cases of conflict, the potential inclusion of a study was discussed until consensus was reached.

2.5. Data collection

Of the final included studies, data were extracted for characteristics of the general study (e.g., year of publication, authors), participants (e.g., age, gender), posterior fossa tumor (e.g., histology, location), tumor treatment (e.g., treatment protocol, extent of resection), language assessment (e.g., tools, language levels assessed) and language outcomes (e.g., test scores, group comparisons). A template for data extraction was created and piloted for group and individual data (see protocol). All data were first extracted by the first author (Cheyenne Svaldi) and numeric language data and individual demographic data were verified by the second author (Effy Ntemou). In cases of conflict, results were discussed until consensus was reached.

2.6. Quality assessment of individual studies

The methodological quality of each included study was assessed using the Joanna Briggs Institute critical appraisal tools [25]. These tools were adapted to suit this systematic review (i.e., clinical population, primary outcomes of interest) and a merged checklist was created and piloted (see protocol). All included studies were appraised both by the first author and one of three co-reviewers (Roel Jonkers, Saskia Kohnen or Vânia de Aguiar). A total quality score was calculated for every study. Studies scoring below 50% were excluded from data extraction. This criterion was based on initial piloting of the adapted tool in 20 studies.

2.7. Quality assessment body of evidence

The Grades of Recommendation, Assessment, Development and Evaluation (GRADE) guidelines were used to assess the quality of the body of evidence for every language outcome [26]. Since the present study only included behavioral studies, the certainty of the body of evidence started at low rating.

2.8. Data synthesis

Due to the different measures and comparisons (normative scores, other statistics), a meta-analysis or one sample *t*-test was not deemed appropriate. Instead, a narrative synthesis was conducted using the guidelines for synthesis without meta-analysis (SWiM) [27]. These guidelines were advised in the updated PRISMA guidelines [28] and have been used in other systematic reviews [14]. The data were synthesized using predefined categories, including:

- **Study characteristics:** Study characteristics were summarized for study design, year of publication, country, and the language the articles were written in.
- **Population characteristics:** Sample size, age at assessment, time since surgery, language background, tumor type, and tumor treatment were synthesized.
- **Language outcomes:** The reported language outcomes were grouped by level of language functioning (see Table 1) for group and individual data separately to answer the primary research question. To facilitate interpretation, a language impairment was defined as a performance of 1.5 standard deviations (*z* score of −1.5; *percentile* < 6.5) or more below the population mean. While cut-offs are ultimately arbitrary, this cut-off has been used quite commonly in the literature [29] and clinical guidelines [30]. If insufficient information was provided to meet this criterion, significant differences with a $p < .05$ or an age-equivalent score of more than two years below the patient's age was used to define an impairment.
- **Influence mediators:** Studies reporting on the pre-defined mediators (see protocol) were synthesized to answer the second research question. At the group level, studies that conducted statistical comparisons for one of the mediators were included. At the individual level, individual patient information for the included mediators was summarized.
- **Language assessment tools:** The number of language assessment tools was grouped by language function to answer the third research question. A distinction was made between tests that focus specifically on the assessment of language processing and the identification of language impairments (i.e., language-specific tools) or literacy skills (i.e., literacy-specific tools) and neuropsychological tests (e.g., tests assessing vocabulary within a broader intelligence test). This is important to determine if scores were interpreted from a linguistic perspective.

Since low-quality-studies were excluded, all studies were considered equally in the data synthesis.

Table 1
Description of the language functions with examples of tasks that assess these functions.

Language function	Explanation	Task examples
Lexical-semantics	The ability to process, store and retrieve meanings/word forms.	Picture naming Word-picture matching
Morphosyntax	The ability to process and use grammar. This includes rules of morphology (i.e., word forms) and syntax (i.e., sentence structure).	Grammaticality judgment task Mean length of utterance
Phonology	The ability to produce and discriminate speech sounds. This includes phonological working memory, phonological awareness and retrieval of phonological forms.	Nonword repetition Rhyme judgment
Pragmatics	The ability to flexibly adjust the use and understand language to the characteristics and implied intentions of the other speaker(s), and in general, to the communicative context (e.g., a conversation).	Story generation task (narrative cohesion) Story re-telling task (story grammar)
Reading	The ability to decode written language. This includes reading fluency, accuracy and comprehension.	Speeded word reading Text reading
Spelling	The ability to produce orthographically accurate written forms. This includes word spelling accuracy.	Spelling words to dictation Nonword copying
Verbal learning	The ability to encode and retain familiar and unfamiliar words or sequences of words.	Word list learning Novel word learning

3. Results

3.1. Study selection and quality assessment

Initially, 2526 abstracts were retrieved of which 342 remained after deduplication and abstract screening (87.83% inter-rater agreement). Of these, 340 full texts were assessed for eligibility. Twenty-three studies were excluded from data synthesis due to low methodological quality. Sixty-six studies fit the inclusion criteria (99.42% inter-rater agreement). See Supplementary Materials for the PRISMA flowchart of the study selection process and other reasons for study exclusion.

Notably, only three of the included studies [31–33] conducted a preoperative language assessment. Also, in many studies relevant information was missing, such as education level of the patients and parents, language background and the length of school absence e.g., [34,35]. The quality rating of the body of evidence (GRADE) for the final number of included studies was 'very low' for all outcomes. The main factors contributing to this rating were study design (i.e., observational, small participant groups), inconsistency (i.e., heterogeneity in study populations and outcomes measures) and the precision of estimates (e.g., missing effect sizes, patient loss to follow-up).

3.2. Study characteristics

Sixteen of the 66 studies were merged due to patient overlap [11,13,31,36–48], resulting in 56 separate samples included for the narrative synthesis. Studies were published between 1989 and 2021. Most studies (n = 34) were conducted in English-speaking countries, such as the United States e.g., [34,49] and Australia e.g., [40,43]. Twenty-eight studies reported group data, 10 individual data and 18 both. Some studies reported additional data not included in this systematic review (e.g., group data also including other tumor types [13]). Most studies assessed language at a single time point. Thirteen studies [11,39,40,43,45,48,50–56] reported longitudinal data. Twenty-four studies included a control group. See Appendix C for details on patient characteristics, and the reported language outcomes.

3.3. Population characteristics

In total, language outcomes of 1282 children, adolescents and adults who had childhood posterior fossa tumor surgery were reported. The number of patients varied from one to 91 (*M* (*SD*) = 22.88 (17.89)) across studies. Most patients attended primary or secondary school at the first postoperative language assessment, but age varied considerably (range = 2–36 years). Time since surgery ranged from six days to 31 years at first assessment. Most studies included patients in the oncology follow-up phase (i.e., from the end of tumor treatment until five years after) and in the survivorship phase (i.e., > five years after treatment). Eighteen studies included patients operated for a medulloblastoma, 12 for an astrocytoma and one for an ependymoma. Twenty-four studies included multiple tumor types. In 19 studies, patients were treated with surgery and radiotherapy. In 13 studies, participants only had posterior fossa surgery. In the remaining 23 studies, patients had different tumor treatments. For each of these population characteristics, information was missing in one study. Most studies (59%) included native English speakers.

3.4. Language outcomes

3.4.1. Language functions studied in the literature

Forty-six studies reported language outcomes for groups of patients who had posterior fossa surgery e.g., [46,57,58]. Lexical-semantics e.g., [59–62] (n = 29), reading e.g., [52,63–65] (n = 20) and verbal learning e.g., [61,66–68] (n = 20) were the main focus of research. Spelling e.g., [49,64,69] and phonology e.g., [70–72] were assessed 15 and 14 times respectively. Morphosyntax e.g., [13,33,73] (n = 7) and pragmatics [13,36,48,74] (n = 3) were studied less frequently.

Twenty-eight studies reported individual language outcomes for 256 posterior fossa tumor survivors. In these studies, lexical-semantics e.g., [56,73,75] (n = 22) was also assessed most often, followed by reading e.g., [34,76,77] (n = 15) and phonology e.g., [44,78,79] (n = 15). Twelve studies focused on morphosyntax e.g., [56,62,80] and 10 on spelling e.g., [65,75,76]. Verbal learning e.g., [49,54,81] (n = 9) and pragmatics e.g., [41,45,76] (n = 6) were studied less often.

3.4.2. Reported language impairments

The number of times at which different language functions were assessed varied quite markedly between studies. Therefore, we could not meaningfully compare relative frequencies of occurrence of a language impairment across these functions. However, for each language function (bar pragmatics for the group studies), there were more patients without an impairment than with an impairment (see Figs. 1 and 2). For those groups or individuals for whom impairments were reported, these were distributed across all assessed language functions. In what follows, group-level studies are reported while individual studies are discussed in the next paragraph. Nine out of 29 studies reported group-level impairments (see Fig. 1) for lexical-semantics e.g., [67,82,83] (e.g., reduced vocabulary [55,83] or comprehension [67,84]).

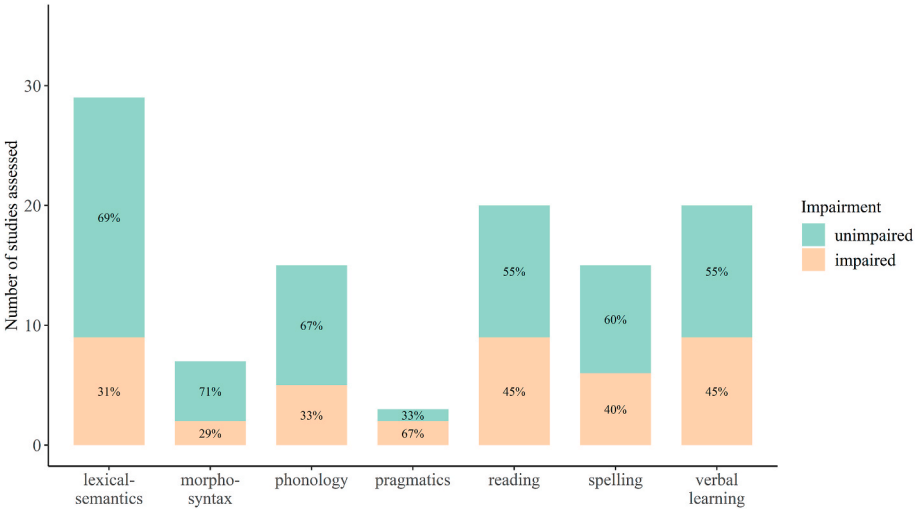

Fig. 1. Language outcomes for groups of patients per level of language functioning (n = 46 studies).

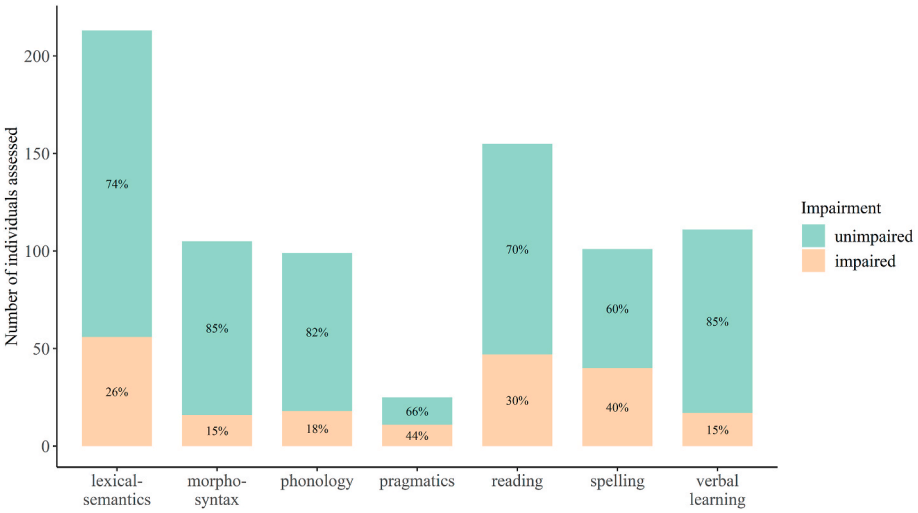

Fig. 2. Language outcomes for 256 posterior fossa tumor survivors per level of language functioning.

Morphosyntactic impairments were reported in two out of seven studies (e.g., sentence formulation deficits [73,82]). Five [70,73,79,85,86] of the 15 studies assessing phonology found an impairment, such as auditory sequential memory [73,79] and long-term verbal memory problems [86]. Two [36,74] out of three studies found pragmatic impairments. Among others, inference [74] and story grammar difficulties [36] were reported. For literacy skills, nine out of 20 studies reported reading impairments e.g., [55,74,77](e.g., problems with reading fluency [70] and comprehension [82]), while six [49,52,55,65,69,82] out of 15 studies reported spelling impairments (e.g., reduced spelling accuracy [49]). Finally, in nine out of 20 studies e.g., [81,85,87,88] verbal learning impairments were observed across all aspects of the auditory retention of words, such as initial encoding and long-delayed recall.

Of the studies reporting language outcomes for individual patients (see Fig. 2), many patients (n = 56/213) had a lexical-semantic impairment, reflected by, for example, reduced vocabulary [51,78]. Morphosyntactic impairments (n = 16/105) included, among others, problems with morphology and expressive syntax [39,73]. Reported phonological impairments (n = 18/99) were, among others, reduced phonological awareness [44,56] and auditory sequential memory deficits [70]. Pragmatic deficits were reported in 11 out of 25 patients and included problems with comprehending figurative language [38,45]. Many patients with spelling (n = 40/101) and reading (n = 47/155) impairments were reported, such as reduced spelling accuracy [34,65] and reading fluency [50]. Verbal learning impairments were also observed in 17 out of 111 patients, with problems reported when learning lists of words [54,81]. Of the 124 patients who were assessed for multiple language functions, 24 had impairments for two or more functions.

Eleven studies conducted a language assessment at multiple time points, showing inconsistent results regarding the persistence of difficulties. Nonetheless, assessments were conducted at very different time points across studies with follow-up ranging from eight months to 14 years. None of the four group studies [52–55] found an impairment at the first postoperative assessment. Two studies reported a long-term decline in average literacy performance [52,55], but it was not described if the patient groups scored in the impaired range on relevant tests. The remaining two longitudinal studies [53,54] found no language impairment at any of the time points investigated.

Eight samples [11,39,40,43,45,48,50,51,56] reported longitudinal data on individuals, with some studies indicating improvements in language functions over time, others indicating decline, yet others indicating persistent deficits. For example, in one case study [56] a multilevel deficit was reported one year after surgery. Five years after surgery, however, only impairments in two out of the five assessed language domains (reading and phonology) persisted. During another comprehensive assessment of two patients, phonological and pragmatic impairments were found one year after surgery which had not been detected six months prior [45]. Another study reported acute lexical-semantic deficits that persisted years after surgery [51].

3.5. Mediators

The possible influence of several mediators on the reported language outcomes was investigated. In this section, every mediator is discussed separately. Possible confounds and interactions between mediators are addressed in the Discussion. For the summary of individual patient data, we counted the number of patients for whom information on a mediator was given and calculated the proportion of individuals that were reported to be language-impaired (Table 2). Due to the heterogeneity of the data, we did not conduct a meta-analysis, but instead describe possible influences of mediators verbally. Results need to be interpreted with this in mind.

3.5.1. pCMS

Overall, there appeared to be an influence of pCMS diagnosis, but not of the length of the mute phase on the language outcomes. Six group studies compared patients with and without pCMS [4,53,64,77,89,90]. Five of these found pCMS to be associated with worse lexical-semantic [4,53], phonological [4], verbal learning [4,89,90] and/or literacy [4,77] outcomes. In two of these studies, however, patients scored within the normal range of performance [4,53]. Similar to the group studies, the individual patient summary suggested a slightly higher incidence of language deficits in pCMS-patients (see Table 2). In terms of the types of language impairments, both in patients with and without pCMS lexical-semantic problems were often reported e.g., [78]. Morphosyntactic impairments e.g., [40,78] were also common in pCMS-patients, while in non-pCMS-patients literacy problems appeared more common e.g., [50,77]. However, as already stated above, these comparisons on frequency of occurrence may be skewed as studies varied in which language skills they assessed.

None of the group studies investigated effects of the length of the mute phase on language outcomes, but the duration was reported for seven pCMS-patients [36,39,51,73,78]. No consistent patterns were found, with language deficits reported in children who were mute for less than a week [36] and in children who were mute for several months [39].

Table 2
Number of language-impaired patients per mediator. Results are provided only for studies that reported individual data and not for group studies for which no individual data were available.

Mediator		N patients with language impairment (%)
Patient characteristics		
Age at diagnosis (n = 110, 23 studies)	< 2y	4/4 (100%)
	2 – 6y	20/40 (50%)
	primary school	23/50 (64%)
	high school	4/16 (25%)
Age at assessment (n = 122, 25 studies)	< 6y	7/17 (41.18%)
	primary school	34/58 (58.62%)
	high school	12/45 (26.67%)
	adult	0/2 (0%)
Gender (n = 89, 23 studies)	female	10/33 (30.30%)
	male	30/56 (53.57%)
Tumor characteristics		
Tumor type (n = 123, 26 studies)	astrocytoma	21/70 (30%)
	medulloblastoma	20/31 (64.52%)
	ependymoma	10/19 (52.63%)
	other	1/3 (33.33%)
Tumor grade (n = 123, 26 studies)	low grade	24/76 (31.58%)
	high grade	28/47 (59.57%)
Tumor location (n = 69, 18 studies)	vermis	21/49 (42.86%)
	left hemisphere	8/24 (33.33%)
	right hemisphere	4/12 (33.33%)
	brainstem	4/5 (80%)
	4th ventricle	12/14 (85.71%)
Tumor size (n = 20, 11 studies)	< 5 cm	11/14 (78.57%)
	> 5 cm (large tumor)	3/6 (50%)
Tumor treatment-related complications and characteristics		
pCMS (n = 76, 21 studies)	yes	12/18 (66.67%)
	no	31/58 (53.44%)
Hydrocephalus (n = 65, 20 studies)	yes	25/40 (62.50%)
	no	8/25 (32%)
Other complications (n = 60, 21 studies)[a]	yes	16/21 (76.19%)
	no	21/39 (53.85%)
Treatment phase (n = 120, 24 studies)	oncology treatment	12/23 (52.17%)
	oncology follow-up	31/72 (43.01%)
	survivorship	7/25 (28%)
Treatment type (n = 113, 26 studies)	only PFS	26/84 (19.05%)
	PFS + CRT	25/39 (64.10%)
Extent of surgery (n = 49, 20 studies)	complete	12/23 (52.17%)
	incomplete	20/26 (76.92%)

pCMS = postoperative cerebellar mutism syndrome; *survivorship* = > 5 years after treatment; *PFS* = posterior fossa surgery; *CRT* = cranial radiotherapy.

[a] Postoperative complications (apart from pCMS and hydrocephalus) that complicated tumor treatment, such as hemorrhage and infections (e.g., meningitis, shunting infections).

3.5.2. Patient characteristics

Regarding age at diagnosis, older children might have more favorable postoperative language outcomes. Four out of 12 group studies reported that children who were older at diagnosis performed better for literacy [74], verbal learning [89] or lexical-semantics [70,83]. Other studies (n = 8) found no relation between age at diagnosis and these language functions [49,55,58,66,77,81,86,87]. Individually, impairments were less frequently reported in patients attending high school at the time of surgery (Table 2). Further, all four patients below two years of age at diagnosis had a postoperative language deficit [11,50].

No immediate relation between age at assessment and the language outcomes was found. Across all age groups, a broad range of language deficits was observed e.g., [73,88]. Five group studies compared age groups [52,67,77,79,90], showing inconsistent results. For example, while Kieffer-Renaux et al. [67] found no relation between age at assessment and literacy, other studies reported worse literacy outcomes in children [52,77] who were older at the time of assessment. Individually, language deficits were most often reported in children between two and 12 years, but not in adults (Table 2).

Generally, there was no consistent relation between gender (reported as binary, male/female in all studies) and language outcomes. Only one of four [49,57,81,86] group studies reported an influence of this mediator, with females performing worse than males for verbal learning [86]. The individual patient data did suggest that males were more often impaired than females.

It was not possible to assess the influence of language background (e.g., mono- vs multilingual) or handedness on the language outcomes because of insufficient information.

3.5.3. Tumor characteristics

Overall, worse language outcomes in medulloblastoma than astrocytoma patients were reported. Five [60,73,81,83,85] out of six [60,73,81,83,85,91] group studies comparing multiple tumor types reported worse outcomes in medulloblastoma patients, although these patients were not always language-impaired [60]. The individual patient data also confirmed this tendency (Table 2). However, language deficits were also reported in ependymoma e.g., [44,52] or astrocytoma e.g., [51,77] patients.

It appears that tumor grade has an impact on language outcomes, with six [4,59,60,73,81,85] out of seven [4,59,60,73,81,85,91] group studies reporting more severe or a higher occurrence of language impairments in high grade tumors. Individually, this tendency was also confirmed (see Table 2).

No consistent patterns were found for tumor location. Three out of five studies reported worse outcomes in patients with tumors in the right compared to the left cerebellar hemisphere and/or vermis [66,73] or in vermal compared to hemispheric tumors [83]. The other two group studies reported no influence of tumor location (i.e., vermis, left or right cerebellar hemisphere) on language outcomes [34,60]. The individual patient data suggested a similar incidence of language impairments for tumors in the cerebellar hemispheres or vermis. Most impairments were reported for tumors invading the brainstem (n = 5) or fourth ventricle (n = 14), but the sample size was small.

The influence of tumor size could only be described for studies on individuals, with a higher occurrence of language impairment in smaller (< 5 cm) tumors.

3.5.4. Tumor treatment characteristics

In general, no clear influence of hydrocephalus was found on language outcomes. Only two [55,90] out of five [4,49,55,57,90] group studies reported a negative effect of hydrocephalus on the language outcomes, but individually there were more reports of language impairment in patients who had hydrocephalus (Table 2). Because of irregularities in reporting and missing information across studies regarding the severity of hydrocephalus, when it occurred (i.e., pre- or postoperatively) and how it was measured, we were unable to distinguish these categories. No influence of other postoperative complications (see footnote in Table 2) was reported in group studies [57,67,86], but individually language impairments were more often reported after, for example, shunting or infection [50].

Similarly, no consistent patterns were found for treatment phase. Only two [49,87] out of seven [49,81,83,86,87,89,90] group studies found a relation between this mediator and the language outcomes. These studies described opposite patterns with Reeves et al. [87] reporting worse reading accuracy and spelling outcomes with increased time since radiotherapy, while Johnson et al. [49] found spelling impairments to be resolved in the survivorship phase (here 10 years after surgery). Individually, language deficits were reported least often in the survivorship phase and most often during tumor treatment (Table 2). Yet, mixed patterns of impairment were reported in all phases following tumor treatment e.g., [69,74,85].

Regarding treatment type, overall a negative effect of adjuvant radiotherapy on language performance was reported. Radiotherapy was consistently associated with worse language outcomes in all five group studies comparing treatments [4,57,60,81,83]. Further, a higher

frequency of language deficits was reported in individuals who received radiotherapy (Table 2). Again, patients still performed within the normal range in several studies [57,60] and language deficits were also reported following posterior fossa surgery alone e.g., [31,88]. Further, several group studies reported an increased radiation dosage to be associated with worse language performance e.g., [52,84]. The effect of radiation dosage could not be assessed individually, since nearly all patients received standard-dose radiotherapy. No study compared differences between proton and photon therapy.

Overall, no effect of the extent of resection was found. Higher resected volume was positively correlated with verbal fluency in one group study [83], but two other studies found no effect for this mediator [49,64]. Individually, language impairment was reported more often in patients for whom surgical resection was incomplete.

Similarly, mixed results were found for lesion site (dependent on tumor location), with group studies (n = 5) and individual data (not reported in Table 2 because of large variability) suggesting worse language outcomes in right-sided [31,42,90], left-sided [79], and vermal lesions e.g., [51]. Other studies found no immediate relation [80,83]. It was not possible to investigate the influence of surgical incision site or school absence because no information was reported for these mediators.

3.6. Language assessment tools

To answer the third research question, the tools used to assess language were considered. The largest number of different tools was used to evaluate lexical-semantics (n = 33). Of these, 48.48% (n = 16/33) were language-specific tools (i.e., specific to language as opposed to other cognitive functions) commonly used in other language-impaired populations (e.g., post-stroke aphasia, developmental language disorders). Standardized tests focused on vocabulary size e.g., [74,75], verbal fluency e.g., [62] and single-word comprehension e.g., [51,66]. Only two studies assessed verbs with researcher-developed tasks looking into verb generation [31,80]. Nine different tools were used to assess morphosyntax. These tools are commonly used in other language-impaired populations, such as the ScreeLing in post-stroke aphasia [78,92]. Many tools focused on expressive syntax, measured by, for example, mean length of utterance [73]. Twenty different tests (n = 8/20 language-specific; 40%) evaluated phonology, generally focusing on verbal working memory, measured by, for example, story recall [50] or forward digit span [61]. Six studies assessed phonological awareness e.g., [93]. Pragmatics was assessed by seven different tests (n = 6/7; 85.71% language-specific). These assessed, among others, narrative cohesion [36] and comprehension of figurative language [93]. For reading and spelling, respectively, 11 (n = 6/11; 54.66% literacy-specific) and 10 (n = 5/10; 50% literacy-specific) different tools were used. Different aspects of literacy were evaluated, such as reading fluency e.g, [77] and reading or spelling accuracy [34]. Finally, the 10 different tools used for verbal learning all evaluated auditory retention of nouns in a neuropsychological context. It should be noted, however, that some tasks may reflect multiple language functions. For example, while story recall was included here as a pragmatic measure, it may also reflect morphosyntax. Few studies conducted a comprehensive postoperative language assessment e.g., [4,43]. In a large proportion of the evaluations, tests were part of a cognitive assessment ('intelligence test') or an academic achievement battery e.g., [61,62]. Also, most studies reported quantitative and not qualitative data (e.g., error analyses [73]).

4. Discussion

4.1. Language outcomes of children, adolescents and adults who had posterior fossa surgery

Based on our narrative synthesis of 66 studies, we found that, although language was reported to be intact in the majority of the patients e.g., [64,80], many studies did report postoperative impairments across all language functions. These were characterized by a large interindividual heterogeneity.

These results suggest that children who had a posterior fossa tumor are at risk for language impairment. However, methodological irregularities make it impossible to reliably evaluate the risk of developing a language impairment. Most importantly, there were almost no studies that assessed preoperative language skills. We appreciate that this kind of evaluation is often not a priority in the phase immediately before tumor treatment. In addition, the delineation of pre-existing language disorders that are independent of the tumor is complicated if children have had a tumor for a relatively long time (in which case there may be preoperative tumor-related difficulties). Nonetheless, evaluating preoperative language status, including preoperative language difficulties caused by tumor growth or presence, would still aid in accurate interpretation postoperative language outcomes [33]. Further, different areas of language were assessed a different number of times, using different measures. In accordance with previous studies, a large heterogeneity was observed in both the type and severity [11,14] of the language outcomes. For example, a patient could present with an impairment limited to one language function or a multi-level impairment. Impairments were reported across all phases of treatment (i.e., from the acute until survivorship phase), but findings of longitudinal studies looking at the persistence of deficits were inconsistent and few. Also, the language evaluations that were conducted varied in the language functions assessed across time points and in time intervals. Finally, since few studies conducted a comprehensive language assessment, it is impossible to determine whether an impairment was truly absent or simply not observed because of a lack of comprehensive testing.

While the data synthesized in this review indicate that most patients after posterior fossa surgery do not have language impairments, many patients do show impairments at one or more of the following language levels: lexical-semantic, literacy, phonology and verbal learning. Since the number of observations across the different language areas were unequal, we cannot comment on how frequent impairments in these language areas occur nor could we reliably identify strengths in the language profile.

4.2. Mediators

Our mediator synthesis indicates that language impairments occur irrespective of pCMS-diagnosis, but also that pCMS might be related to worse language outcomes. The literature did describe more morphosyntactic problems in pCMS-patients, while literacy problems were more common in non-pCMS-patients. Nonetheless, it was difficult to identify differential patterns of impairment, as few studies conducted statistical comparisons between the two groups, sample sizes were unequal in the individual data summary and because of the issues already alluded to in terms of different assessments across studies. No study investigated the effects of the length of the mute phase or the severity of pCMS on the language outcomes. Especially the length of the mute phase might be relevant since this could influence language development – expressive language in particular [10].

In contrast to previous reports e.g., [13], we failed to find consistent patterns for most other included mediators. However, our synthesis suggested patterns related to age (a lower occurrence of or less severe language impairment in children older at diagnosis) and tumor type (higher occurrence and impact of language impairment in medulloblastoma and high-grade tumor patients). Although we could not always determine if groups were comparable, our data indicated a negative influence of craniospinal radiotherapy on language outcomes. Its neurotoxic effects on infra- and supratentorial neural structures are well known and might have increased the complexity of the reported language deficits [94]. Further, radiation dosage was associated with worse language outcomes on a group level e.g., [52,84], but unfortunately,

missing data did not allow us to assess this individually. Further research is necessary, in which the molecular subtype of the tumor should also be considered because of its importance in defining radiation dosage [95].

Interplay between these mediators should be considered since malignant tumors are generally treated with postoperative radiotherapy [3]. Research has also shown that younger children are more susceptible to the neurotoxic effects of radiotherapy [96]. Methodologically, many studies looked at their variable of interest without controlling for other mediators. Further, the number of studies investigating most mediators was small, with small sample sizes. Several of the mediators we aimed to investigate were not described in the studies, such as language background and the duration of school absence. These are clinically relevant since reduced language proficiency or long school absence can have substantial effects on language outcomes and literacy [97,98]. Lastly, we were only able to provide a narrative review when statistical analyses of mediators would allow for a more robust evaluation of whether and how mediators may impact language outcomes.

4.3. Language assessment

Lexical-semantics, verbal learning and literacy were assessed most often across studies. Morphosyntax and pragmatics were assessed much less, even though several studies reported impairments e.g., [39]. Further, most tools were part of a broader intelligence or academic assessment. These neuropsychological tools might not be suitable to detect language impairments in posterior fossa tumor survivors, who may have more subtle or different language impairments than other language-impaired populations [10]. While these assessments give an idea of the language performance in posterior fossa tumor survivors, they do not identify the nature of the observed impairments or discuss these in the context of language development. For example, a clinical score on an expressive vocabulary test might indicate a semantic impairment (i.e., incomplete or missing word meanings), a lexical impairment (i.e., problems retrieving words from memory) or a phonological impairment (i.e., problems producing sounds). Also, reduced vocabulary size might reflect a lack of existing knowledge or retrieval ability, or a problem with acquiring novel words. Since children who underwent posterior fossa surgery are often faced with a long and multidisciplinary rehabilitation trajectory, identifying the nature of the language impairments might lead to more efficient rehabilitation. A bigger focus on qualitative (e.g., error types) language analysis could assist in framing the direction for therapy.

Overall, administered tasks focused on noun and not on verb knowledge and learning. Yet, verbs are more susceptible to impairment in children with language disorders [99], learned later [100] and more difficult to acquire [101] than nouns. Thus, verb processing might be impaired more often or more severely in children who had posterior fossa surgery, but reports on such problems are absent now.

The absence of uniform patterns of language impairment and presence of several methodological irregularities allow us to formulate many possibilities for future research. To gain further insights into the language problems in this population, large-scale research is needed in which a uniform and comprehensive assessment is conducted. For example, joint testing protocols between research teams and clinics can help achieve at scale studies. These studies should try to include larger and more equal groups of different mediators, so that the cause of the impairments can be identified. More information regarding language-specific factors should also be gathered, such as language background. This information will be crucial to guide clinical practice and inform families about the consequences of tumor treatment.

5. Conclusion

The results of this review confirm that posterior fossa tumors and subsequent treatments can have negative effects on language and that these can encompass all levels of language functioning. Yet, several gaps in language assessment remain, such as a preoperative assessment. For clinical practice and research purposes, a comprehensive postoperative language follow-up is necessary, using language-specific tests that identify the nature of possible impairments. In research studies, a preoperative language assessment is also necessary to accurately interpret postoperative language outcomes and to evaluate whether impairments are caused by tumor treatment. A preoperative assessment could, for example, consist of a communication checklist or a short spontaneous speech assessment. A comprehensive language follow-up can guide language rehabilitation and can benefit long-term language outcomes and quality of life. The methodological restrictions of our research decrease the generalizability of our findings but do stress the uncertainty regarding the language outcomes in this population despite a wealth of studies.

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Declaration of competing interest

The authors have no conflicting interests declare.

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Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejpn.2023.12.005.

Appendix A

Table A.1
Deviations from the original systematic review protocol (https://osf.io/5j6by/).

Section protocol	Deviation
Eligibility criteria	Originally, it was stated that participants had to be younger than 18 years of age at assessment. It was deemed relevant to also include adults that were operated on during childhood because this could provide further insight into the long-term language outcomes in our population.
Data collection - Data extraction	Due to the large number of included studies, only the numeric language data and individual demographic data were checked by the co-reviewer (Effy Ntemou).
Data collection - Data items	Treatment phase was added to the list of included mediators related to tumor treatment.

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Table A.1 (*continued*)

Section protocol	Deviation
Quality assessment individual studies	In the systematic review protocol, it was described that the original versions of the Newcastle Ottawa Quality Assessment Scale and Joanna Briggs Institute checklists would be used for quality assessment. To ensure consistency and since it was better suited for the research questions of this review, it was deemed better to use one adapted checklist across all study designs.
Data synthesis	Due to the large heterogeneity in study designs, participant groups and language assessments, a meta-analysis was not deemed appropriate. Instead, a narrative synthesis was conducted.

Appendix B

Table B.1
Search string for PubMed.

(posterior fossa surgery OR cerebellar surgery OR infratentorial surgery OR posterior fossa tumo* OR cerebellar tumo* OR infratentorial tumo* OR cerebellar neoplas* OR posterior fossa neoplas* OR infratentorial neoplas*)
AND
(child*[Title/Abstract] OR adolescen*[Title/Abstract] OR teen*[Title/Abstract] OR youth*[Title/Abstract] OR paediatr*[Title/Abstract] OR pediatr*[Title/Abstract] OR young*[Title/Abstract])
AND
(language OR linguistic* OR spontaneous speech OR mutism OR verbal learning OR word learning OR comprehension OR vocabulary OR semantic* OR lexic* OR naming OR anomi* OR literacy OR reading OR orthograph* OR writing OR spelling OR phonolog* OR gramma* OR agrammat* OR synta* OR morpho-synta* OR verb generation OR aphasi* OR verbal fluency OR pragmatic*)

Appendix C

Table C.1
Characteristics of the included studies in the systematic review (n = 66).

Study	Number of patients	Age range (in yy; mm)	Time since surgery	Language function(s) assessed	Language outcome
Group					
Callu et al., 2009 [59]	39	6;1–12;7 years	*M* (*SD*) = 2;11 (2) years	lexical-semantics	no impairment
Cámara et al., 2020 [4]	36 (+ 34 controls)	4–18 years	no info	lexical-semantics, phonology, verbal learning, reading, spelling	no impairment
Docking et al., 2016 [13]	10 (+ 10 controls)‡	5;6–14;11 years	0;6–8;5 years	lexical-semantics, morphosyntax, pragmatics	no impairment
Grieco et al., 2020 [53]	36	2–15;10 years at first assessment	minimum 1 year after radiotherapy	lexical-semantics	no impairment
Grill et al., 1999 [84]	19‡	5–15;6 years	*M* (*SD*) = 5;4 (3;4) years after radiotherapy	lexical-semantics	lexical-semantic impairment
Hodgson, 2018 [82]	21 (+ 22 controls)	16;2–21;9 years	2;3–16;10 years	lexical-semantics, morphosyntax, reading, spelling	all assessed levels impaired
Holland et al., 2015 [46]; *2016* [47]†	36	7;9–18;9 years	0;10–13;2 years	reading	no impairment
Hopyan-Misakyan, 2008 [60]	37 (+ 37 controls)	7;4–16;10 years	1;1–9;3 years	lexical-semantics	no impairment
Kieffer-Renaux et al., 2000 [67]	36	6;2–26;1 years	*M* (*SD*) = 4;4 (4;8) years after radiotherapy	lexical-semantics, verbal learning, reading	all assessed levels impaired§
Law et al., 2017 [61]	25 (+ 20 controls)	8;1–19 years	1;2–13;8 years	lexical-semantics, verbal learning, phonology	no impairment
Mabbott et al., 2008 [57]	64‡	11 years	**radiotherapy:** range = 8;7 years **surgery only:** range = 10;10 years	lexical-semantics, phonology	no impairment
McGahan, 2013 [86]†	14–21 (+ 14–21 controls; depending on test)	6–16 years	1–11 years	lexical-semantics, verbal learning, phonology	phonological, verbal learning impairment
Menendez-Narvaez et al., 2017 [32]	5 (+ 4 controls)‡	6;3–11;6 years	0; 3–0;4 years at first assessment	lexical-semantics	no impairment
Merchant et al., 2014 [52]	76‡	1–17 years	within 3 months at first assessment	reading, spelling	longitudinal reading & spelling impairment
Moberget et al., 2015 [88]	20 (+ 26 controls)	18–30 years	5–22 years	lexical-semantics, verbal learning	all assessed levels impaired
Moxon-Emre, 2013 [55]	91‡	no info	0;1–8;9 years at first assessment	lexical-semantics, verbal learning, reading, spelling	all assessed levels impaired
Mulhern et al., 1998 [69]	10-11 (depending on test)‡	11;4–16;10 years	6;1–9;10 years	reading, spelling	all assessed levels impaired
Mulhern et al., 2001 [68]	20‡	6;4–21;6 years	1;10–11 years after radiotherapy	verbal learning	no impairment
Nagel et al., 2006 [89]	40 (+ 40 controls)	5;1–17 years	0;1–2;5 years	verbal learning	verbal learning impairment
O'Neil et al., 2020 [72]	24‡	2;6–14;6 years	0;11–10;9 years	phonology, verbal learning	no impairment

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Table C.1 (*continued*)

Study	Number of patients	Age range (in yy; mm)	Time since surgery	Language function(s) assessed	Language outcome
Palmer et al., 2010 [64]	44	1 year post-diagnosis	1 year	lexical-semantics, phonology, reading, spelling	no impairment
Pletschko et al., 2018 [58]	14 (+ 14 controls)	15–31 years	3–21 years	lexical-semantics, verbal learning	no impairment
Quintero-Gallego et al., 2006 [91]	18 (+ 12 controls)	**AS:** *M* (*SD*) = 11;7 (3;2) years **MB:** *M* (*SD*) =13; 2 (1; 11) years	0;5–12;7 years	verbal learning	no impairment
Reeves et al., 2006 [87]	38	6;4–16;1 years	−0;1–4;9 since start radiotherapy	verbal learning, reading, spelling	verbal learning impairment
Rønning et al., 2005 [85]	23	16;10–33;1 years	10;2–21;10 years	phonology, verbal learning	all assessed levels impaired
Starowicz-Filip et al., 2020 [90]	44 (+ 30 controls)	7–16 years	0;1–2 years	verbal learning	no impairment
Steinlin et al., 2003 [66]	24	7;7–26;8 years	2;1–18;3 years	lexical-semantics, verbal learning	no impairment
Vaquero et al., 2008 [83]	20 (+ 12 controls)	6;8–18 years	0;5–10;11 years	lexical-semantics	lexical-semantic impairment
Individual					
Brown et al., 1992 [56]	1	6;9 years at first assessment	1;1 year at first assessment	lexical-semantics, morphosyntax, phonology, verbal learning, reading	all assessed levels impaired§
Callu et al., 2008 [50]	1	4;7 years at first assessment	3;1 years at first assessment	lexical-semantics, phonology, verbal learning, reading	phonological, verbal learning§, reading impairment§
De Smet et al., 2009 [51]	5‡	3;1–11;6 years at first assessment	6 weeks–0;6 years at first assessment	lexical-semantics, verbal learning, morphosyntax, phonology	lexical-semantic impairment
De Witte et al., 2017 [78]	1	12 years	6 weeks	lexical-semantics, phonology, morphosyntax	lexical-semantic, morphosyntactic§ impairment
Docking et al., 2005 [93]; *2016* [13]; *Docking & Knijnik, 2021* [45]·†	2‡	7;8–14;11 years at first assessment	0; 6–6;3 years at first assessment	lexical-semantics, morphosyntax, phonology, reading, spelling, pragmatics	phonological impairment
Docking et al., 2007 [43]; *2016* [13]; *2021* [45]; *Murdoch et al., 2004* [44]· †	4	7;9–13 years at first assessment	0;6–3 years at first assessment	lexical-semantics, morphosyntax, reading, spelling, pragmatics	pragmatic impairment
Levisohn et al., 2000 [75]	18	3;8–16;6	0;1–1;9 years	lexical-semantics, phonology, verbal learning, reading, spelling	lexical-semantic, phonological, reading, spelling impairment
Lewis & Murdoch, 2010 [38], *2011* [37], *2013* [11]·†	4 (+ 20 controls)	5;1–10;3 years at first assessment	0;3–4;4 years at first assessment	lexical-semantics, morphosyntax, pragmatics§	all assessed levels impaired
Martinez et al., 2015 [76]	1	9 years	no info	lexical-semantics, phonology, reading, spelling, pragmatics	spelling impairment
Murdoch et al., 2004 [44]; *Docking et al., 2016* [13]·†	8 (+ 8 controls)	3;9–13;3 years	0;7–8;5 years	lexical-semantics, phonology, morphosyntax, pragmatics, reading, spelling	all assessed levels impaired
Both					
Aarsen et al., 2004 [62]	23	6;7–22;11	1–8;10 years	**group:** verbal learning, lexical-semantics, morphosyntax **individual:** verbal learning reading	**group:** no impairment **individual:** verbal learning impairment§
Ait Khelifa-Gallois et al., 2015 [77]	17 (+ 61 controls)	7–17 years	1–15;7 years		**both:** reading impairment (individual§)
Beebe et al., 2005 [34]	47–48‡	3–18 years	*M* (*SD*) = 108 (78) days	reading, spelling	**group:** no impairment **individual:** reading & spelling impairment§
Benavides-Varela et al., 2019 [71]	11 (+ 11 controls)	6;2–12;6 years	0;7–5;6 years	phonology	**group:** no impairment **individual:** phonological impairment§
Brinkman et al., 2012 [70]	20	21–36 years	12–25 years	reading, verbal learning, phonology, lexical-semantics	**group:** reading, verbal learning, phonological impairment **individual:** lexical-semantic, phonological, verbal learning, reading impairment§
Di Rocco et al., 2011 [33]	23‡	3–16 years	before chemo-/ radiotherapy	lexical-semantics, phonology, verbal learning, morphosyntax	**both:** no impairment§
Frank et al., 2007 [31], *2008* [42]·†	8–12 (+ 11 controls)	8–18 years	6–113 days	**group:** lexical-semantics, reading, spelling **individual:** lexical-semantics, morphosyntax, phonology, reading, spelling	**group:** lexical-semantic impairment **individual**§**:** morphosyntactic, reading, spelling impairment
Hardin, 2007 [54]	10–20 (depending on test)‡	4;1–18;2 years	2 weeks–0;2 years at first assessment	**group:** lexical-semantics, phonology, verbal learning, reading, spelling **individual:** lexical-semantics, phonology, verbal learning, reading	**group:** no impairment **individual:** all assessed levels impaired§
Hudson et al., 1992 [36, 48]· †	17 (+ 16 controls)	4;5–16;1 years at first assessment	6 weeks–9;2 years at first assessment	**group:** pragmatics **individual**: lexical-semantics, morphosyntax	**group:** pragmatic impairment **individual:** lexical-semantic, morphosyntactic impairment

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Table C.1 (*continued*)

Study	Number of patients	Age range (in yy; mm)	Time since surgery	Language function(s) assessed	Language outcome
Johnson et al., 1994 [49]	13‡	9–35 years	no info	**group:** reading, spelling **individual:** lexical-semantics, verbal learning	**both:** all assessed levels impaired
Kirschen et al., 2008 [79]	12 (+ 12 controls)	6;6–19;5 years	*M* (*SD*) = 5;6 (3;1) years	lexical-semantics, phonology	**group:** phonological impairment **individual:** no impairment
Kristiansen et al., 2021 [74]	6–16 (depending on test)‡	9–33 years	*M* (*SD*) = 12;2 (4;7) years	**group:** reading, spelling, lexical-semantics, pragmatics, phonology **individual:** lexical-semantics verbal learning	**group:** lexical-semantic, pragmatic, reading impairment **individual:** lexical-semantic impairment§
Levitch et al., 2022 [81]	25 (+ 17 controls)	6–16 years	1–10 years		**both:** verbal learning impairment (individual§)
McDonald, 2005 [65]	13‡	13;7–27;11 years	11–20 years	lexical-semantics, reading§, spelling§	**group:** spelling impairment **individual:** all assessed levels impaired
Murdoch & Hudson-Tennent, 1994 [39]; *Hudson et al., 1989* [40], *Hudson & Murdoch, 1992* [41]†,‡	19 individuals; 7 (+ 7 controls) group‡	4;5 (13;10 group) −16;10 years	**individual:** 1;2–9;2 years **group:** 1;11–7;3 years	**group:** lexical-semantics, morphosyntax, reading, spelling **individual:** lexical-semantics§, morphosyntax, pragmatics, reading, spelling	**group:** no impairment **individual:** all assessed levels impaired
Richter et al., 2005 [80]	11 (+ 27 controls)	9–19 years	1–13;5 years	lexical-semantics, morphosyntax, reading, spelling	**both:** no impairment
Riva & Giorgi, 2000 [73]	26	6–12;6 years	minimum five to six weeks after surgery, before adjuvant treatment	lexical-semantics, morphosyntax, phonology	**both:** all assessed levels impaired
Smith, 2016 [63]	19 (+ 23 controls)‡	17–35 years	5–31 years	reading	**group:** no impairment **individual:** reading impairment

† = Studies merged because of patient overlap; ‡ = Different number of participants than originally reported (demographics should be interpreted with caution); § = Recoding of language outcomes based on 1.5 *SD* criterion not possible; *AS* = Astrocytoma; *MB* = Medulloblastoma.

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