Title

Complex syntax in the isolated right hemisphere: Receptive grammatical abilities after cerebral hemispherectomy

Authors

de Bode, Stella
Smets, Lieselotte
Mathern, Gary W
et al.

Publication Date

2015-10-01

DOI

10.1016/j.yebeh.2015.06.024

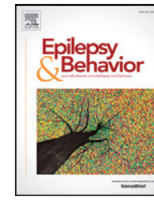
Peer reviewed

Epilepsy & Behavior 51 (2015) 33–39

Contents lists available at ScienceDirect

Epilepsy & Behavior

journal homepage: www.elsevier.com/locate/yebeh



Complex syntax in the isolated right hemisphere: Receptive grammatical abilities after cerebral hemispherectomy

Stella de Bode [a,*], Lieselotte Smets [b], Gary W. Mathern [c,d,e], Stanley Dubinsky [f]

[a] The Brain Recovery Project, Los Angeles, CA, USA
[b] Department of Linguistics, University of Utrecht, The Netherlands
[c] Departments of Neurosurgery and Psychiatry & Biobehavioral Sciences, Mattel Children's Hospital, David Geffen School of Medicine, University of California, Los Angeles, CA, USA
[d] The Intellectual and Developmental Disabilities Research Center, Mattel Children's Hospital, David Geffen School of Medicine, University of California, Los Angeles, CA, USA
[e] The Brain Research Institute, Mattel Children's Hospital, David Geffen School of Medicine, University of California, Los Angeles, CA, USA
[f] Linguistics Program, University of South Carolina, SC, USA

ARTICLE INFO

Article history:
Received 23 March 2015
Revised 29 May 2015
Accepted 2 June 2015
Available online 4 August 2015

Keywords:
Cerebral hemispherectomy
Syntax
Seizure control
Rasmussen's encephalitis

ABSTRACT

Objectives: In this study, we explored the syntactic competence of the right hemisphere (RH) after left cerebral hemispherectomy, on the premise that it (syntactic competence) is known to be one of the most strongly *left*-lateralized language functions. As basic syntactic development for individuals in this subject pool has already been extensively explored, we focused instead on the investigation of complex syntactic constructions that are normally acquired later in childhood, i.e., between 7 and 9 years of age.
Methods: Grammatical competence in 10 participants who had undergone *left* cerebral hemispherectomy was compared to that of a group of normally developing children, with the two groups matched by the size of their vocabulary. The two tests we used for this research were created by the 1st language acquisition linguists and were designed to test sets of constructions categorized and differentiated by the order in which they are normally acquired and by the type of grammatical competence that they involve.
Results: We found that both groups followed the same developmental sequence of syntactic development with five (50%) postsurgical participants (all with prenatal etiologies) reaching nearly mature command of sentence grammar. Seizures negatively impacted performance on all tests.
Conclusions: The isolated RH has the potential to support the complex grammatical categories that emerge relatively late in the normal acquisition of English by native speakers. Successful performance may be related to the timing of the initial insult and seizure control following hemispherectomy.

1. Introduction

The capacity of the right hemisphere (RH) to support oral and written language, together with the related issues of brain lateralization, remains an area of intensive research. Perhaps the best test of what the RH can do in isolation found in cases of language development following cerebral left hemisphere (LH) hemispherectomy. Although studies of language reorganization following local resections are informative, it should be understood that the outcomes of LH hemispherectomy are quite distinct from these cases [2] in that the substrate of a restored function is clear in contrast to the lesion studies where recovered function may reflect the involvement of the RH only, perilesional areas of the LH, or some combination of both [1,2]. Any investigation of hemispherectomy patients is inevitably accompanied by the methodological difficulties of small sample sizes and heterogeneous clinical variables; nevertheless, studies of language development in these patients do have the potential to shed light on both the strengths and limitations of the RH and might ultimately help in the development of informed interventions [3]. In this study, we explored the RH's syntactic competence, known to be one of the most strongly *left*-lateralized language functions [4].

Various aspects of sensorimotor and cognitive development following both right and left hemispherectomy have been reported in the literature [5–8]. The results have been found to vary, with the transfer of functions after hemispherectomy seeming to depend on both clinical factors and the nature of the function. Thus, transfer of specific functions cannot be taken for granted. For example, reading after hemispherectomy presents an area of major difficulty for patients, with only 42% mastering it [9]. Basic syntactic development for individuals in this subject pool has been extensively explored with respect to various languages, with the published studies reporting that the syntactic capacity of the isolated RH varies from poor to nearly normal [10–12]. Not all of these reports on posthemispherectomy language development distinguished

* Corresponding author at: The Brain Recovery Project, 107 South Fair Oaks Ave., Suite 316, Pasadena, CA 91105, USA.
E-mail address: sdebode@brainrecoveryproject.org (S. de Bode).

http://dx.doi.org/10.1016/j.yebeh.2015.06.024
1525-5050/

clearly between the syntactic development that is attained in the RH when it is enlisted in acquisition from the very beginning (i.e., when an early hemispheric insult occurs before lateralization), as opposed to the development of syntactic competence in the RH after lateralization has begun to unfold (i.e., the time when an insult occurs after language acquisition nominally progressed to the age of syntax acquisition).

Furthermore, few studies specifically tested subjects' capacity for syntactic comprehension [11–13]. Using two tests that were specifically created for the testing of syntactic development, the present study investigated RH competence in the largest-to-date posthemispherectomy cohort and with respect to complex syntactic structures that are acquired late by normally developing children.

The development of language when the RH is forced to support it (i.e., in the absence of a functioning left hemisphere [LH]) has attracted attention from a number of cognitive disciplines. The five studies reporting syntactic development after left hemispherectomy used a variety of tests on a cumulative total of 5 individuals (across all the studies) with various or unknown etiologies [11–15]. Furthermore, the subjects reported on in these studies were patients who were acquiring any one of three distinct languages (English, French, and Italian), mostly precluding, thereby, any direct linguistic comparison of the reported results. The results of these studies varied, ranging all the way from severe impairment in an individual who became sick and underwent hemispherectomy following a few years of normal development [12] to nearly normal performance in a participant with a prenatal insult [13].

Additionally, only a few of the language tests administered were ones that specifically targeted syntactic competence. For example, Vargha-Khadem and colleagues [15,16] used the Test of Receptive Grammar (TROG, [17]). However, given that TROG is normed for ages 4 to 16 years, it necessarily incorporates elements that are quite outside the range of, and which do not strictly test, basic syntactic knowledge. For example, TROG includes items that test subjects' competence in regard to conversational pragmatics and discourse structure. These are facets of language competence that, in contrast to syntactic maturation, continue to develop long after 9 years of age, when basic syntactic competence is more or less complete [18].

Three additional patients with left-sided resections were reported on by [16]. In their study, these patients had worse outcomes than patients with right hemisphere resections. However, their results did not report TROG test outcomes separately, and it is, furthermore, hard to interpret the results of their use of the CELF-R (Clinical Evaluation of Language Function) test, since it, too, includes nonsyntactic items and measures.

In one of few studies specifically targeting syntax, Curtiss and Schaeffer [10] analyzed error rates in the use of functional morphemes (i.e., grammatical/nonlexical; e.g., subject pronouns and modal or auxiliary verbs) by five pairs of posthemispherectomy participants (right resection and left resection; matched for etiology and age factors). The results of their investigation yielded weak support for left hemisphere advantage in grammatical morpheme production and strong support for the language acquisition potential of the isolated hemisphere (both right and left).

Given evidence suggesting that basic syntactic competence can be successfully acquired by children with an isolated RH [10,19], we focused on testing subjects' mastery of complex constructions that healthy children typically acquire relatively late in the course of their development (i.e., between the ages of 7 and 9 years, cf. [18]). Specifically, we tested constructions, such as nonfinite complement clauses and relative clauses, which children under the age of 9 tend to misapprehend [20].

In order to assess patients' competence with respect to this level of grammatical complexity, the present study tested, and compared with healthy controls, 10 participants with an isolated RH, who were at least 9 years of age and who were several years postsurgery compared 10 participants with an isolated RH, who were at least 9 years of age and who were several years postsurgery (*median 7 years*). We predicted that many participants from the posthemispherectomy group would still be in the process of acquiring advanced syntactic constructions, and we chose our control group based on this prediction. The control group of typically developing children, aged 7–10 years, was chosen to allow us to determine whether posthemispherectomy participants were following the same acquisition trajectory as healthy children at a comparable developmental stage in their mastery of the most complex common structures of English. Based on prior research and on our own observations, we hypothesized that advanced syntactic constructions would be an area of difficulty for the majority, but not necessarily all, of our participants, and that the control group would consistently score higher than patients on all grammatical measures.

2. Methods

Institutional Review Boards at both the University of South Carolina and the University of California, Los Angeles approved this study. To assess and analyze syntactic development of individuals after *left* cerebral hemispherectomy, we compared their performance with that of a cohort of healthy controls using two tests of language development and linguistic competence, CYCLE and Sentence Judgment (see below for full description). Patients' and controls' families all signed informed assent and consent forms including Health Insurance Portability and Accountability Act (HIPAA) authorizations. This study was not a clinical trial and is, therefore, not registered.

2.1. Cohort description

2.1.1. Individuals after left cerebral hemispherectomy: recruitment and clinical variables

Recruited for this study were ten (10) consecutive participants who had undergone *left* cerebral hemispherectomy performed to arrest seizures associated with (i) prenatal insult: perinatal infarct, PI ($n = 7$), and (ii) postnatal Rasmussen encephalitis, RE ($n = 3$).

Originally, 6 participants with RE were recruited for the study, but, as 3 of them had severely limited speech outcome together with apraxia of speech, they were, thus, excluded. All participants were tested while participating in gait therapy [21].

2.1.1.1. Etiology and clinical variables. Our recruitment efforts were designed to enable us to report on the largest group of posthemispherectomy participants but also to reduce the heterogeneity of the clinical group as much as possible. In this regard, we selected patients having two etiologies that, by nature of their associated underlying lesions, are known to disrupt LH functioning during a discrete time window which can be fairly precisely determined. In addition, both etiologies have a low incidence of bilateral involvement. Finally, additional efforts were undertaken to confirm the integrity of the remaining hemisphere in all patients (see below). All participants were a part of a large 2-week-long study that required a minimum IQ of 75 [21].

In all, seven individuals histopathology results were consistent with a middle cerebral artery (MCA) stroke in utero. The rest of the participants had a clinical history and histopathology consistent with RE. Clinical history and neuroimaging results were reviewed both presurgically and postsurgically to check for the presence of any visible missed connections remaining between the two hemispheres and on the status of the remaining RH. The remaining RH of participants reported on in this study was described as “without overt lesions” or “nearly normal” by corresponding neurologists. The clinical variables in Table 1 were abstracted from the records as previously described [22]. These variables included age at seizure onset, age at surgery, age at testing, whether the child was taking antiepileptic drugs (AEDs), and whether the child was having seizures at the time of testing. All participants had undergone psychoeducational testing.

Table 1
Clinical variables and test results for participants after left hemispherectomy.

	Clinical variables					Behavioral testing			
	Etiology	Age at testing, yrs	Age at seizure onset	Age at surgery, yrs	Seizures controlled with AED[b]	CYCLE			Sentence Judge, # correct/50
						Receptive vocabulary	Highest level passed	Developmental Index[a]	
1F	PI	10	3	4	Yes	76	5.5	0.6	33
2F	PI	11	5	10	No seizures	80	7.5	0.8	48
3F	PI	13	5	8	No seizures	94	9	1	49
4F	PI	14	4	10	No seizures	70	6.5	0.7	46
5F	PI	14	4	6	No seizures	99	9	1	44
6M	PI	20	7	11	No seizures	103	9	1	49
7M	PI	21	0.5	10	No seizures	94	8.5	0.9	44
Median		14	4	10		94	8.5	0.9	46
8M	RE	9	1	2	Yes	74	3.5	0.4	
9M	RE	14	2	4	Yes	93	6.5	0.7	40
10M	RE	17	11	12	No seizures	74	3.5	0.4	39
Median		14	2	4		74	3.5	0.4	44

[a] Developmental Index, Highest level passed in CYCLE (corresponding to years) divided by 9.
[b] Antiepileptic drugs.

For the group with PI, *age at testing* varied from 10 to 21 years (*median*, 14 years), with *age at seizure onset* from 1 to 7 years (*median*, 4 years) and *age at surgery* from 4 to 11 years (*median*, 10 years). For the group with RE, *age at testing* was 9, 14, and 17 years, with *age at seizure onset* 1, 2, and 11 years and *age at surgery* 2, 4, and 12 years, respectively.

2.1.1.2. Language characteristics. All 10 participants (females, n = 5) were from monolingual English-speaking families. Presurgical evaluations of their language abilities were not available, probably because of severe seizure activity. Interviews were conducted with each participant's parents, in order to obtain an account of the participant's acquisition of language and their level of literacy, as well as to review their Individual Education Plans (IEPs).

All parents of participants after PI stated that their children's language development had seemed appropriate from about 24 months of age after an initial delay and until seizures became uncontrolled and language deterioration began. Some of these children could barely speak at the time of their surgery, while others retained a few words and signs. The early onset of seizures (*median*, 4 years) along with the severity of their seizure disorder (up to 250 seizures per day) is assumed to have disrupted language acquisition, such that none of these children were able (prehemispherectomy) to attain anything like mature syntactic proficiency. As a matter of fact, these patients had all suffered from a deterioration of their speech, as reported by their families. Language recovery following surgery was described as fast, and within 4–5 weeks postsurgery, children had attained their preseizure levels. All participants at school returned to the same grade level without missing a school year, with either no professional intervention or (at most) 1 weekly session with a Speech Language Pathology (SLP) professional. All participants in the group with PI had age-appropriate speech and comprehension of language at testing, based on data using previously published assessments [23]. All families reported no history of left-handedness in the family, and each child's use of her left hand from early on was, most likely, due to the hemiparesis associated with stroke.

In contrast, parents of participants with RE stated that initial development was normal with all developmental milestones reached on time. Seizures occurred following major milestones, such as sitting and walking, and rapidly disrupted normal functioning. Only patient 10M had acquired literacy and was classified as gifted by his school. However, by the time of surgery, he had lost the ability to communicate and at enrollment in the study was the most impaired of these 3 participants in his language production. All three participants with RE had reduced speech outcomes consisting of 1–4-word responses to questions and no spontaneous speech. When asked to describe their trip to SC where the study took place, they produced 2–4 simple predication sentences with prompting from the tester. Comprehension of language was at age level, and all participants could participate in a 2-week-long therapy camp with no special accommodations for language. The participants with RE all had very limited literacy (i.e., they could read only a few words and were able to write their own names). All families reported no history of left-handedness with children being typical right-handers before seizures started.

2.1.2. Controls

In choosing to explore the most complex constructions supported by the isolated RH, we hypothesized that all posthemispherectomy participants would either attain *mature grammatical competence* (at 9 years in normally developing children) or would exhibit *near-mature levels of syntactic development* comparable with the levels of healthy 7–9-year-old children. Because one posthemispherectomy participant, 8M, did not pass a pretest for Sentence Judgment, leaving us with nine subjects, we enrolled nine control participants between ages 7 and 10 years (*median*, 8.5 years) from a local day school to take part in the study, Table 2.

2.1.3. Comparing two groups

We matched the two groups in their verbal intelligence expressed by the size of their receptive vocabulary measured by PPVT (for detailed description, see below).

2.2. Testing

Three tests, described below, were orally administered to collect information on subjects' and controls' syntactic development (in the first two cases) and their lexical knowledge (in the last case). Individual scores for all tests are presented in Tables 3 and 4.

Table 2
Controls: Chronological age and test scores, standard scores 100 ± 15.

	Chronological age, years	Receptive vocabulary SS	CYCLE, level passed	Sentence Judgement, /50
N101	8	104	8	49
N102	9	85	9	49
N103	7	106	7	45
N104	9	93	7.5	48
N105	10	84	9	48
N106	7	86	6.5	47
N107	9	96	9	48
N108	8	95	7.5	38
N109	9	75	7.5	36
Median	9	93	7.5	48

Table 3
CYCLE levels 7–9, % correct answers for each grammatical construction.

Level	Content	%, correct	
		Subjects, n = 5	Controls, n = 9
7.1	Before & after	95	91
7.2	Preposition BY	90	98
7.3	Preposition FROM	95	89
7.4	Preposition WITH	100	100
7.5	Double embedding	88	93
7.6	Possessive — 's	96	82
7.7	S–S relative clause	100	93
7.8	Subject vs object pronoun	96	96
7.9	Tense/aspect: WILL	68	84
	Median level 7	95	93
8.1	Object clefts	80	80
8.2	O–S relative clauses	100	91
8.3	Story comprehension	100	93
8.4	Verb plural	84	51
	Median level 8	92	86
9.1	Complex semantics	84	78
9.2	Negative passive	72	84
9.3	O–O relative clause	64	89
9.4	S–O relative clause	36	42
	Median level 9	68	81
	Median, Levels 7–9	90	89

2.2.1. CYCLE-R

One test used was the receptive portion of Curtiss and Yamada Clinical Language Evaluation (CYCLE), consisting of sentence–picture matching tasks [24]. This instrument consists of a battery of short tests distributed over 9 age levels (2 to 9 years). The higher levels of CYCLE-R (levels 7–9) contain several subtests, with each one focusing on a distinct area of syntactic knowledge usually acquired by normally developing children at the targeted age. Each test item involves the oral presentation of a stimulus sentence or phrase, followed by the subject selecting the one picture (out of 2 or 4) that best illustrates the meaning of the prompt. According to the protocol for CYCLE-R, a subject must successfully complete all the individual subtests at a given level in order to move to the next higher level (n.b., each grammatical subtest within a level is considered successfully passed if at least 4 of 5 items are answered correctly). A subject that successfully completes at least 75% (but not 100%) of the subtests in a single level will have a half-year test level added to their score. If the child completes less than 75% of the subtests in a level, the testing stops and their development is rated as being at the last level successfully completed. For example, if a child successfully completes all the subtests in level 7 and 75% of the subtests in level 8, a test age of 7.5 years is recorded (if the child had only completed 50% of the subtests in level 8, a test age of 7.0 would have been recorded). Age 9 corresponding to level 9 is the ceiling level, and an individual successfully passing this level is considered to have fully mature sentence grammar comparable to that of an adult. See Appendix A for the examples of sentences.

Since all participants after hemispherectomy were of an age when native speakers usually have full command of grammar (i.e., ≥9 years), we focused our testing on the highest three age levels of the test (CYCLE levels 7–9), which primarily assess syntactic competence, rather than on the lower (i.e., earlier) levels, in which lexical competence is the focus.

Table 4
Sentence Judgment, cumulative % of correct answers in each grammatical category.

Grammatical construction, n = 50 (4 sentences each, 2 correct & 2 incorrect)	Subjects n = 9	Controls n = 9
Subcategorization A	83	97
Subcategorization B	89	94
Present continuous BE + ING	94	97
X-BAR	94	92
Agreement	92	97
Case A	97	97
Case B (total 2 sentences)	94	94
Tense	83	94
Do-support	94	94
WH-question	70	83
Negation	92	83
Subject–auxiliary inversion A	63	75
Subject–auxiliary inversion B	83	81
Median	92	94

2.2.2. Sentence Judgment

This test (unpublished, S. Curtiss UCLA) requires a subject to judge whether a sentence spoken by the examiner is acceptable or not. It is assumed that a subject will correctly judge these sentences only if they have syntactic ability required to do so. There are a total of 50 sentences to judge, of which half are correct and the other half are not. Thirteen specific syntactic constructions are included in the instrument, so that each construction is tested four times: twice grammatically and twice with corresponding ungrammatical sentences (except in one construction for which only two stimuli are provided, accounting for the total number of 50 test sentences). The 13 different constructions tested include verb subcategorization (i.e., the lexical determination of a verb's objects), present progressive inflection (i.e., *be* + verb-*ing*), placement of relative clause modifiers, subject–verb agreement, negation (i.e., the placement of *not* into a sentence), temporal adverb and verb tense concord (i.e., the matching of temporal adverbs (e.g., *yesterday*) with the tense (e.g., past) of the sentence), subject/object pronoun placement (i.e., the correct use of the subject and object forms of pronouns (e.g., *he* and *him*)), and three separate tests on question formation—one involving the assessment of *yes–no* question formation with subject–auxiliary inversion (i.e., in which an auxiliary verb such as *have* or *will* precedes the subject), one examining *wh*-question formation (i.e., in which a question word such as *what* or *who* is placed at the beginning of the sentence), and one assessing question formation with "*do*-support" (i.e., in which *do* or *does* appears before the subject when there is no auxiliary verb available to be placed there). See Appendix A for examples.

Although the sentence judgment task was designed to test syntactic competence, it is actually the case that some of the constructions tested (e.g., verb subcategorization) might be better regarded as measures of semantic or lexical syntax–semantics interface knowledge, rather than as measuring purely syntactic competence. Other constructions used in the instrument, such as the evaluation of the grammaticality of negation and of tense concordance, are also often regarded as engaging semantic, rather than syntactic, resources [25]. Regardless of the linguistic category to which each of these phenomena are ascribed (lexical, syntactic, or semantic), they all do, nevertheless, involve the manipulation of function words and inflectional affixes (e.g., subject–verb agreement) and/or the syntactic movement of elements within the clause (e.g., subject–auxiliary inversion), and we saw no grounds for a priori excluding any of them.

An example of a grammatically correct sentence and its ungrammatical counterpart are given in (1) and (2).

(1) Does Bill arrive in the morning? (*Yes–no* question formation: GOOD)
(2) *Arrives Bill in the morning? (*Yes–no* question formation: BAD)

In this instance, the subject is expected to know that main (i.e., non-auxiliary) verbs such as *arrive* do not precede the subject in question-formation, and that a tensed form of *do* is used instead.

2.2.3. Receptive vocabulary

To measure the receptive vocabulary size of individual subjects and controls and use this as a baseline measure for matching the two groups, we calculated standard scores from the Peabody Picture Vocabulary

Test, PPVT [26], 100 ± 15. The range of PPVT standard scores for subjects was from 70 to 103, *median* = 87. For controls, this range was from 75 to 106, *median* = 93. The two groups did not significantly differ in their performance (p = 0.254, Mann–Whitney, 2 tail).

3. Data analyses and results

3.1. CYCLE

3.1.1. Levels

Seven out of nine controls successfully passed CYCLE's levels corresponding to their chronological ages (7, 8, or 9) with 2 children aged 9 years passing level 7.5 only (Table 2). For each posthemispherectomy participant, testing was initiated at level 7, with the goal of having all individuals complete levels 7–9 if possible. In conducting these tests, we found that 5 participants of the 10 were unable to successfully pass CYCLE level 7, suggesting that they had not yet reached a level of competence corresponding to 7 years of age in healthy speakers. These 5 were then tested on CYCLE levels 2–6 to establish their highest level of competence. Their syntactic development was found in the range corresponding to healthy children between 3.5 and 6.5 years. Participants in this subgroup of 5 subjects were aged from 10 to 17 years (*median*, 14 years) and had undergone hemispherectomy for RE, n = 3, and PI, n = 2, with 4 to 10 years postsurgery (*median*, 6 years).

3.1.2. Grammatical categories

We further investigated the details of the performance of controls (all of whom had attained levels 7–9) and that of the posthemispherectomy participants who successfully reached levels 7–9 — indicating near-mature grammatical competence (n = 5, *median* age at testing 14 years). These two groups were matched using the size of their receptive vocabulary as described in the Methods section. To investigate the differences between posthemispherectomy participants and our controls in their mastery of specific grammatical constructions, we calculated *the number of correct answers* for each of the 17 subtests in levels 7–9 (as was pointed out above, each subtest targets a particular grammatical category or construction such as agreement, preposition use, relative clauses, and negative passive) and found no differences between the two groups ($U = 123.5$, p = .48). The results are shown in Table 3. Both groups followed a similar trajectory with the number of correct answers decreasing from levels 7 to 9. Level 9 proved difficult for all participants with the lowest *median* scores occurring in this category (68 for subjects and 81 for controls). Descriptively, the two groups were roughly similar on a construction involving complex semantics on level 9, controls had fewer errors on negative passive and object–object relative clause (statistically n.s.) and both groups struggled with the subject–object relative clause construction.

3.2. Sentence Judgment

Both groups were tested on the 13 construction types (50 sentences total), see Table 4.

In a manner similar to CYCLE, percentages of correct answers were calculated for each syntactic construction, and a nonparametric Mann–Whitney test, two-tailed, was applied. There were no statistically significant differences between the two groups (p = .32).

3.3. Clinical variables

There were significant correlations of syntactic test scores (CYCLE and Sentence Judgment) and the presence of seizures, $r_s = 0.79$ and 0.83, $p < .05$, respectively, with correlations for other clinical variables. The size of receptive vocabulary did not correlate with the presence of seizures, age at seizure onset, and years postsurgery.

3.4. Correlations with receptive vocabulary

Correlations between CYCLE and PPVT scores were found in the group of posthemispherectomy individuals ($r_s = 0.87$, $p < .05$), but no correlations were found in Sentence Judgment and PPVT. In contrast, no correlations between either CYCLE or Sentence Judgment were found in controls.

4. Discussion

The contributions to syntactic knowledge of the LH inferior frontal, temporoparietal, and occipitotemporal regions, as well as the arcuate fasciculus and external capsule fibers have been firmly established in adults [27–29]. This strong lateralization emerges later in childhood from a much more distributed and bilateral circuitry [30,31], although the exact nature of the processes driving it remains unclear [32].

The capacity of the isolated RH to support the most complex grammatical constructions remains unknown. The variety of tests conducted and results reported in previous studies, ranging from severe impairment [12] to nearly normal performance [13], do not settle the question. The present study was, thus, prompted by the need to determine the maximum capacity of the RH in isolation to support receptive syntactic tasks.

4.1. Test performance

The two tests we used were created by L1A (1st language acquisition) linguists and were designed to test sets of constructions categorized and differentiated by the order in which they are normally acquired and by the type of grammatical competence that they involve. Accordingly, there were distinct tasks (populated with appropriate experimental items) that tested receptive competence in the following: (i) morphosyntax (e.g., plural affixation), (ii) tense marking (e.g., the expression of tense on the verb), (iii) complex structures (e.g., relative clause embedding), and (iv) grammatical rules (e.g., passive). Modalities in the two tests differed, with CYCLE being a picture-matching test and Sentence Judgment being a traditional sentence acceptability task (i.e., asking a subject to judge whether a sentence is acceptable or not). The latter modality is considered exceedingly difficult, in that it involves many more levels of processing than what is required for the simple matching of a sentence with a picture [33]. We nevertheless used it, as it has been firmly established that children are able to respond to the task in a reliable way [34].

The most important finding of this study is that the isolated RH has the potential to support most of the complex grammatical categories that emerge relatively late in the normal acquisition of English by native speakers. Five participants with perinatal lesions, 50% of the posthemispherectomy group, completed CYCLE levels 7–9, thus, achieving near-mature grammatical proficiency. Furthermore, there was no difference in the levels of competence as both subjects and controls performed similarly on all grammatical constructions tested on both CYCLE and Sentence Judgment. It is worth noting that not all categories were found to have been fully acquired by both groups. For example, subject–object relative clauses were difficult for both groups with accuracy ranging between 36% and 42%, respectively. Nevertheless, both groups followed the same developmental progression with the highest scores in level 7 and lowest in level 9.

4.2. Etiology

Reports in the literature have previously suggested that etiology may play a role in language outcomes, with better outcomes in children who have unilateral etiologies that present at an earlier age, e.g., perinatal infarct and Sturge–Weber syndrome [13,15]. Our data may be interpreted as providing cautious support for this claim. In our study, only individuals with early prenatal infarct reached nearly mature syntax, suggesting that when the LH is not available from early on, its RH counterpart has capacity to support syntactic development. However, just having an early insult does not guarantee successful grammatical acquisition, as evidenced by the fact that 2 participants after PI, 1F and 4F, did not reach levels associated with complex grammatical constructions. Interestingly, both participants have been retested on CYCLE at age of 15 and 19 years. While 1F reached level 7.5, thus, adding 2 more years of grammatical development in 5 chronological years between testings, participant 4F remained at level 6.5 suggesting that etiology is indeed an important factor in defining the outcomes but is not the only variable that influences full maturation of grammar. While perinatal insult and very early language development in the RH are often associated with good outcomes similar to what we found in this study, early seizure onset and other individual variables may disrupt this process.

Three out of the 5 individuals who did not reach levels 7–9 were diagnosed with RE, and it is tempting to suggest that late insult associated with this etiology plays a role in the outcome. It has been previously shown that syntactic development supported by the isolated right hemisphere seems to be especially compromised if *left* resection follows a period of normal language development. Unfortunately, in this very small sample, the alternative explanation is the presence of seizures postsurgery. The presence of seizures was strongly associated with worse outcomes for both tests reported here. It is necessary to note that in 6 consecutive patients with RE who were initially enrolled in this study, 3 had practically no expressive language at all and had to be excluded. A separate line of research focusing on RE and language/literacy development in this population is necessary in order to better understand what seem like pervasive deficits resulting from disrupted language lateralization.

4.3. Correlations with receptive vocabulary

An analysis of correlations between the receptive syntactic processing competence of our participants and other measures of their cognitive abilities is beyond the scope of this paper (one of the obstacles in this regard being the difficulty of finding controls matched for IQ [i.e., >70 and <90] who do not have other neurological conditions). That said, we did explore correlations between measures of their receptive vocabulary abilities, per the PPVT test, and their CYCLE scores. A report from Stark and McGregor [11] suggested that children after left resection perform more strongly on the items that tap semantic resources as opposed to items that require morphosyntactic knowledge. In this study, the posthemispherectomy participants demonstrated strong correlations between the results of CYCLE and PPVT, in contrast to the results recorded for controls. Receptive vocabulary tends to be the most spared function following hemispherectomy [16], possibly because of its bilateral cortical representation [35], and increased reliance on these lexical resources may reflect compensation processes following novel demands on the right hemisphere [36]. Alternatively, this correlation may represent prolonged reliance upon the semantic network, which develops much earlier than syntax in healthy children [31]. It is anticipated that future functional imaging studies in this population may shed light on the interface of syntactic and semantic processing in the isolated RH.

4.4. Limitations

It is important to explicitly acknowledge the limitations of our study. While acknowledging it to be possible that controls outperforming patients is a (partial) result of differences in general intelligence, we, nevertheless, take the position that the variability in the acquisition among the patients themselves lends support to the conclusions we have drawn. Additionally, we present results as measured at one point in time after surgery. As mentioned above, we do not know how long patients may continue to develop language skills after surgery, even though it seems that it takes a much longer time to do so, when contrasted with the developmental path of controls. Next, although this study enrolled the largest group reported so far, the numbers are still small. Finally, we note that our control group — which reflected our focus on both qualitative and quantitative aspects of the developmental acquisition of syntactic structures mastered around the age of 7–9 years by normally developing children — was matched to our subjects on the measure of "verbal age" (i.e., verbal IQ). This was preferable to a match by "chronological age" (CA), since such a matching of our subjects with healthy controls aged 9–20 would inevitably have produce a "ceiling effect". The study might have benefitted from the addition of a second control group matched for "mental age" (as our subjects were assessed at 5–15 years by this measure), and future studies might consider the advantage of having both types of controls to measure against subjects. Another limitation encountered in the measurement of "verbal age" (and matching this with controls) was our reliance on the PPVT measure (which has been shown to be a better measure of vocabulary than intelligence). The measures used might have been improved with the addition of an "expressive" vocabulary test (e.g., Expressive One-Word Picture Vocabulary Test [EOWPVT]). However, the etiologies associated with our subject population precluded the addition of expressive measures (apraxia being a common outcome of hemispherectomy). Furthermore, expressive measures might also have introduced an extraneous contrast between participants after infarct and participants after RE, the latter group having severely reduced expressive capacity (and complete aphasia in some cases) following the onset of seizures and then hemispherectomy.

5. Conclusions

In this study, we compared 10 posthemispherectomy individuals and healthy controls on their mastery of syntactic categories that are fully acquired relatively late in childhood. Based on our previous research, we hypothesized that the majority of posthemispherectomy participants would experience significant difficulty on the most advanced grammatical constructions. Using the normal age of acquisition for these constructions as a metric, i.e., 7–9 years in healthy children, we recruited controls from the appropriate age group matched on the size of receptive vocabulary to our posthemispherectomy group.

Our hypothesis was only partially supported. The finding that 5 out of 10 participants successfully mastered specific grammatical constructions suggests that, following left hemispherectomy for a very early prenatal lesion, the isolated RH is capable of developing a mature syntactic system. We did not find any differences between these individuals and healthy children at the same stage of grammatical maturation. At the same time, strong correlations between syntactic measures and vocabulary size in subjects only may suggest that posthemispherectomy patients rely upon their lexical knowledge much more than do healthy children in a compensatory strategy of the RH. The presence of seizures correlated with both tests administered but had no effect on the vocabulary size.

The capacity of the isolated RH to support syntax has been suggested in earlier studies (see above) and has been further supported here by showing that 5 participants have reached levels of nearly mature speakers. Our data also suggest that there always will be those who will not acquire adult-like command of syntax, and etiology may be just one variable among other factors. Further studies are necessary to investigate why fully automatic mastery of the most complex syntactic categories occurs in some but not all individuals and whether different neuroanatomical substrates mediate and define syntactic development with an isolated RH given its increased reliance on semantics as found in this study.

Funding

This study was supported by NIH R01 NS38992, R21 HD050707 to GWM/SdB and The Brain Recovery Project.

Acknowledgments

We would like to sincerely thank all families who participated in this research for their courage and the willingness to help other children. We are also grateful to Susan Curtiss (Department of Linguistics, UCLA) for her permission to use these two tests in this research.

Conflict of interest disclosure

None of the authors has a conflict of interests to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.yebeh.2015.06.024.

References

[1] Staudt M. Reorganization after pre- and perinatal brain lesions. J Anat 2010;217:469–74.
[2] Baciu M, Perrone-Bertolotti M. What do patients with epilepsy tell us about language dynamics? A review of fMRI studies. Rev Neurosci 2015;8:1–19.
[3] Pulsifer MB, Brandt J, Salorio CF, Vining E, Carson BS, Freeman JM. The cognitive outcome of hemispherectomy in 71 children. Epilepsia 2004;45:243–54.
[4] Papoutsi M, Stamatakis EA, Griffiths J, Marslen-Wilson WD, Tyler LK. Is left fronto-temporal connectivity essential for syntax? Effective connectivity, tractography and performance in left-hemisphere damaged patients. Neuroimage 2011;58:656–64.
[5] Backlund H, Morin C, Ptito A, Bushnell MC, Olausson H. Tactile functions after cerebral hemispherectomy. Neuropsychologia 2005;43:332–9.
[6] Benecke R, Meyer BU, Freund HJ. Reorganization of descending motor pathways in patients after hemispherectomy and severe hemispheric lesions demonstrated by magnetic brain stimulation. Exp Brain Res 1991;83:419–26.
[7] Cummine J, Borowsky R, Winder FS, Crossley M. Basic reading skills and dyslexia: three decades following right versus left hemispherectomy for childhood-onset intractable epilepsy. Epilepsy Behav 2009;15:470–5.
[8] Danelli L, Cossu G, Berlingeri M, Bottini G, Sberna M, Paulesu E. Is a lone right hemisphere enough? Neurolinguistic architecture in a case with a very early left hemispherectomy. Neurocase 2012;1:1–23.
[9] Moosa AN, Jehi L, Marashly A, Cosmo G, Lachhwani D, Wyllie E, et al. Long-term functional outcomes and their predictors after hemispherectomy in 115 children. Epilepsia 2013;54:1771–9.
[10] Curtiss S, Schaeffer J. Syntactic development in children with hemispherectomy: the I-, D-, and C-systems. Brain Lang 2005;94:147–66.
[11] Stark RE, McGregor KK. Follow-up study of a right- and a left-hemispherectomized child: implications for localization and impairment of language in children. Brain Lang 1997;60:222–42.
[12] Trudeau N, Colozzo P, Sylvestre V, Ska B. Language following functional left hemispherectomy in a bilingual teenager. I. Brain Cogn 2003;53:384–8.
[13] Mariotti P, Iuvone L, Torrioli MG, Silveri MC. Linguistic and non-linguistic abilities in a patient with early left hemispherectomy. Neuropsychologia 1998;36:1303–12.
[14] Vanlancker-Sidtis D. When only the right hemisphere is left: studies in language and communication. Brain Lang 2004;91:199–211.
[15] Vargha-Khadem F, Carr LJ, Isaacs E, Brett E, Adams C, Mishkin M. Onset of speech after left hemispherectomy in a nine-year-old boy. Brain 1997;120:159–82.
[16] Liégeois F, Cross JH, Polkey C, Harkness W, Vargha-Khadem F. Language after hemispherectomy in childhood: contributions from memory and intelligence. Neuropsychologia 2008;46:3101–7.
[17] Bishop DVM. TROG: Test for Reception of Grammar. Manchester: Chapel Press; 1982.
[18] Chomsky N. The acquisition of syntax in children from 5 to 10. Cambridge, MA: MIT Press; 1969.
[19] de Bode S. Language supported by the isolated right hemisphere. Interdepartmental program applied linguistic. UCLA; 2001.
[20] Diessel H. The acquisition of complex sentences. Cambridge: Cambridge University Press; 2004.
[21] Fritz SL, Rivers E, Merlo A, Mathern GW, de Bode S. Intensive mobility training postcerebral hemispherectomy: early surgery shows best improvements. Eur J Phys Rehabil Med 2011;47:1–9.
[22] Hemb M, Velasco TR, Parnes MS, Wu JY, Lerner JT, Matsumoto JH, et al. Improved outcomes in pediatric epilepsy surgery. The UCLA experience, 1986–2008. Neurology 2010;74:1768–75.
[23] Curtiss S, de Bode S, Mathern GW. Spoken language outcomes after hemispherectomy: factoring in etiology. Brain Lang 2001;79:379–96.
[24] Curtiss S, Yamada J. Curtiss–Yamada Comprehensive Language Evaluation (CYCLE); 2012.
[25] Hornstein N, Grohmann K, Nunes J. Understanding minimalism. Cambridge: Cambridge University Press; 2005.
[26] Dunn LM, Dunn DM. Peabody Picture Vocabulary Test. 4th ed. San Antonio, TX: PsychCorp; 2007.
[27] Dapretto M, Bookheimer SY. Form and content: dissociating syntax and semantics in sentence comprehension. Neuron 1999;24:427–32.
[28] Griffiths JD, Marslen-Wilson WD, Stamatakis EA, Tyler LK. Functional organization of the neural language system: dorsal and ventral pathways are critical for syntax. Cereb Cortex 2013;23:139–47.
[29] Vigneau M, Beaucousin V, Hervé PY, Jobard G, Petit L, Crivell F, et al. What is right-hemisphere contribution to phonological, lexico-semantic, and sentence processing? Insights from a meta-analysis. Neuroimage 2011;54:577–93.
[30] Brauer J, Friederici AD. Functional neural networks of semantic and syntactic processes in the developing brain. J Cogn Neurosci 2007;19:1609–23.
[31] Hahne A, Eckstein K, Friederici AD. Brain signatures of syntactic and semantic processes during children's language development. J Cogn Neurosci 2004;16:1302–18.
[32] Minagawa-Kawaia Y, Cristiàa A, Dupouxa E. Cerebral lateralization and early speech acquisition: a developmental scenario. Dev Cogn Neurosci 2011;1:217–32.
[33] Schutze C. Grammaticality judgments. In: Hogan PC, editor. The Cambridge encyclopedia of the language sciences. Cambridge: Cambridge University Press; 2011. p. 349–50.
[34] de Villiers PA, de Villiers JG. Early judgments of semantic and syntactic acceptability by children. J Psycholinguist Res 1972;1:299–310.
[35] Wright P, Stamatakis EA, Tyler LK. Differentiating hemispheric contributions to syntax and semantics in patients with left-hemisphere lesions. J Neurosci 2012;32:8149–57.
[36] Lidzba K, Staudt M, Wilke M, Krageloh-Mann I. Visuospatial deficits in patients with early left-hemispheric lesions and functional reorganization of language: consequence of lesion or reorganization? Neuropsychologia 2006;44:1088–94.