Syntactic development in children with hemispherectomy: The Infl-System

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1. Introduction

Linguistic theory, acquisition theory, and neurolinguistic theory are all concerned with determining the characteristics and properties of the human biological endowment for grammar and grammar acquisition. In this paper we will examine one aspect of grammatical development in children who have undergone hemispherectomy to control intractable epilepsy. Our objective is to investigate language development in children who have undergone hemispherectomy, the removal of one hemisphere of the brain, as a way to gain insight into the potential of each cortical hemisphere to subserve grammatical development. A second objective is to provide evidence regarding whether and/or when their grammars include functional categories.

The focus of this paper is the functional category INFL, which stands for 'inflection', and subcategories of INFL, or I, for short.
We will examine whether and how the grammars of children who have undergone right or left hemispherectomy embody the I-system. Note that after a left hemispherectomy a person has only a right hemisphere, and after a right hemispherectomy a person has only a left hemisphere.

There are thus two main objectives, and two related sets of issues involved in this work: the neurolinguistic questions regarding the capacity of each hemisphere to subserve grammatical development and the theoretical acquisition issues regarding the principles operative in grammatical development. Specifically, we refer to whether the functional category systems are part of Universal Grammar and therefore are part of every natural grammar, child or adult. Let us first turn to the neurolinguistic questions and issues.

2. Neurolinguistic questions and issues

There is an enormous literature pertinent to the linguistic and neurolinguistic issues at play which for the sake of time we summarize here in only the broadest strokes. The literature on the representation and processing of grammar in the adult brain paints a rather consistent picture.

Whether considering clinical or experimental, including imaging studies of spoken or sign language, it is the left cerebral hemisphere that is specialized for the representation and processing of grammar in the adult. Indeed, neurobiological and neuroanatomical evidence, even during gestation, support the position that the left hemisphere is "prepotent", preprogrammed, as it were, to mediate grammar and its development.

Despite this evidence, however, the representation and processing of grammar in the brain, *especially in the immature brain*, is not a clear-cut or simple matter. In particular, key questions remain regarding the potential of the right hemisphere to subserve grammar acquisition and the role it may play in grammatical development, even under normal circumstances.

Studies of children with focal lesions indicate that acquired aphasia in children is most often the result of *left* hemisphere damage and that the incidence of aphasia following focal damage of the left hemisphere is equivalent to that of adults. However, the nature and degree of the linguistic impairment reported in acquired aphasia in children is rather variable. A few studies even report language delay and deficits as a result of both left *and* right hemisphere focal damage, implying some involvement of the right hemisphere in language development. These results notwithstanding, the neurological mechanism for the acquisition of language by children with focal damage remains a matter of speculation, for it is unknown whether impaired performance in these cases reflects the best efforts of the damaged left hemisphere, the linguistic performance of the right hemisphere, or some combination of both. The potential of the right hemisphere to serve as the substrate for the acquisition of grammar, therefore, perhaps cannot be determined by studies of focal damage. It is the study of grammatical development subsequent to *hemispherectomy* - the removal of an entire cortical hemisphere - that may best directly address this question.

Many studies of children who have undergone hemispherectomy report an advantage for grammar-learning by the left hemisphere. Day & Ulatowska (1979), in two case studies, report significant grammatical deficits in the left hemispherectomy, the child with only a right hemisphere, while grammatical abilities were areas of relative strength for the right hemispherectomy, the child with only a left hemisphere. In several studies by Dennis and colleagues of people who had hemispherectomies as children the isolated left hemisphere was found to be superior to the right in mediating the computation of grammatical structures. In contrast, Strauss & Verity (1983) and Riva and Gazzaniga (1986) report no linguistic deficits following hemispherectomy in any of their cases.

One can see, therefore, that no consistent pattern of grammatical performance in hemispherectomies has been documented as yet. Thus, the central neurolinguistic question of concern for us remains unanswered, namely *What is the capacity of each hemisphere for grammatical development, and in this particular case, acquisition of the INFL-system?* It is this question which we are addressing.

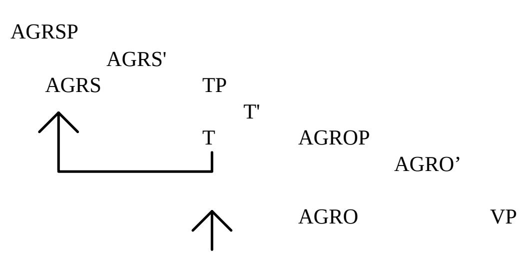
We now turn to the theoretical framework that guides our work.

3. Theoretical framework

The theoretical framework we adopt is that of the Minimalist Program (Chomsky, 1993, 1995). Within this and prior frameworks, numerous structures which had previously been considered morphological structures as distinct from syntactic structures, become part of the syntax. For example, Tense and Agreement morphology is represented in the syntax by separate functional category nodes, namely T for Tense, AGRS for subject agreement and AGRO for object agreement. When inserted into a string, finite verbs carry with them from the lexicon Tense and Agreement features which need to be checked, and can only be checked in the relevant functional projections in the syntax. Therefore finite verbs must move up to T and AGRS either in the overt syntax or at LF, to check their verbal features as illustrated in (2). Auxiliaries and modals are assumed to originate in T and move up to AGRS. Similarly, following analyses in which subject NPs originate within VP, subject NPs move up to spec AGRSP to check their nominal (Case) features. Parallel to finite verbs, non-finite verbs carry non-finite features, such as participle or aspect marking. We assume that these are checked in AGRO. Because of the parallel between AGRO and AGRS, and because AGRO often interacts with T and AGRS: progressive constructions appear with inflected *finite* forms of the auxiliary *"be"* and participles occur with inflected, *finite* forms of the auxiliary *have*, we included AGRO in the structures we examined.

In sum, we assume the following functional categories relevant to the I-system: AGRS, T and AGRO. The relative position of these functional categories is also illustrated in (2):

(2)



Our current focus in examining the grammars of our subjects is on the the I-system because the I-module of the grammar has been shown to be especially vulnerable to brain damage. In both developmental and acquired linguistic pathology, I-system morphemes have been reported to be impaired, at times selectively; that is, alongside relatively intact syntactic and morphological structures of other types. Studies of first language acquisition beyond the "critical period" also report a notable vulnerability of the structures of the I-system. Although it is not the case that other subsystems of the grammar are not vulnerable or impaired in these populations, the literature provides ample data which are compatible with an analysis in which I is comprised of several functional categories, and that this system as a whole or in part can be shown to be selectively vulnerable in atypical or pathological language-learning circumstances.

4. Hypotheses

Given this theoretical and evidential background, we propose the following hypotheses:

First we hypothesize that the children who have undergone left-hemispherectomy and have only a right hemisphere, will evidence a greater error rate in use of I-system elements compared to the right hemispherectomies. Second, we hypothesize that the right hemispherectomied children, those with only a left hemisphere, will develop normal grammars, exhibiting normal developmental patterns with respect to the I-system, eventually attaining the adult I-system in the target language. Third, given the increasing evidence that even early child grammars, normal and abnormal, embody functional categories, we hypothesize that even in the course of protracted and impaired linguistic development, the left-hemispherectomied children will, nonetheless, develop grammars which contain the functional categories of I present in adult English.

5. Subjects

The subjects for the study are children who have undergone hemispherectomy for treatment of catastrophic epilepsy. They are all participants in a multidisciplinary, longitudinal study being conducted at UCLA on the developmental and medical effects of surgical removal of diseased portions of the brain. In this paper we report on a subset of this population, 13 children on whom we collected language samples.

These children ranged in chronological age at the time of surgery from 0;8 to 17;3. and comprise 8 left hemispherectomies and 5 right hemispherectomies. A listing of the subjects, side of surgery, their age at surgery, age at seizure onset, whether the subjects became seizure free after surgery or not, and age at language sample collection, are presented in Table 1:

Table 1: Subjects

subject	side of surg.	age at surg.	age at seiz. onset	seiz. free	age at testing
LB	left	9;6	6;0	no	10;8
GD	left	1;5	infancy	yes	4;5
JF	left	8;6	birth		7;9
JB	left	6;8	birth	no	5;10
GG	left	6;2	0;10	yes	8;0
SM	left	4;0	infancy	yes	9;2
RP	left	1;5	infancy	no	4;9
MW	left	0;8	0;2	no	5;7
SL	right	17;3	12;0	?	17;10
MC	right	14;1	5;0	yes	19;8
JE	right	7;9	birth	deceased	7;10
BB	right	5;11	4;6	no	9;0
MO	right	3;5	2;0	yes	8;1

6. Procedures

The data used for analysis consisted of transcripts of language samples generated from a so-called "Story Game" task in which the child is asked to retell a story she has just heard and to make up a story about one of several topics.

The entire task was videotaped and then transcribed by two independent transcribers. The transcripts were then typed into the CHILDES format (MacWhinney & Snow, 1985) and coded into a scheme worked out by the authors, which includes codes for I-system, C-system, and D-system structures. Additional closed class morphemes were also coded, as were aspects of constituent structure and other syntactic phenomena. Only performance with I-system structures are presented here.

7. The data

Our criterion for including data as evidence of I was limited to the occurrence of overt, phonetically pronounced, I-system morphemes and overt and non-null morphemes of the functional category AGRO. Our criterion for labeling I-system errors was the omission or incorrect use of the structures involved. We excluded from our analyses, however, phonetically null I-morphemes and elements whose phonetic form is unchanged by case-marking; i.e., subject pronouns *you, it*, *this* and *that* and expletives *it* and *there*. By excluding these from the data that we analyzed, we probably have derived conservative estimates of the status of the I-system in our data.

In (4) we present the set of elements associated with each of the different functional categories of the I-system that we included in our analyses. In (5) and (6) we provide example errors related to the structures presented in (4).

(4) *I-system categories coded*

Functional cat.	**Specific morpheme(s)**	**Example**
spec AGRSP	subject pronoun* (*I, we, he, she, they)*	**She** is doing a good job.
AGRS	auxiliaries (*do, is, has*)	He **is** baking me a birthday cake
	modals (*can, must, will* ...)	She **can** speak 11 languages!!
	(*used to, gonna)*	Jean **used to** be a chemist.
	(*hafta, oughtta, etc*.)	I **hafta** finish this paper.
	third singular	Todd sign**s** fluently.
TENSE	regular past	The cop kill**ed** the burglar.
	irregular past	Monica **sang** well.
AGRO	regular past participle	Joe has talk**ed** too long.
	irregular past participle	Jeff has see**n** this before.
	progressive	Todd is go**ing** to class
	infinitive	John will probably **write** a paper
	infinitival *to*	Clara wants **to** get a job

* bearing overt nominative case

(5) *Sample omission errors for the I-system categories coded*

Functional cat.	**Specific morpheme(s)**	**Example**
spec AGRSP	subject pronoun* (*I*, *we*, *he*, *she*, *they*)	__ is doing a good job.
AGRS	auxiliaries (*do, is, has*)	He __ baking me a birthday cake
	modals (*can, must, will …*)	She__ speak 11 languages!!
	third singular	Todd sign__ fluently.
TENSE	regular past	Yesterday the cop kill__ the burglar
	irregular past	Last night I sing__ well.
AGRO	regular past participle	Joe has talk__ too long.
	irregular past participle	Jeff has see__ this before.
	progressive	Todd is go__ to class
	infinitival *to*	Clara wants __ get a job

(6) *Sample errors for the I-system categories coded*

Functional cat.	**Specific morpheme(s)**	**Example**
spec AGRSP	subject pronoun* (*I*, *we*, *he*, *she*, *they*)	**Her** is doing a good job.
AGRS	auxiliaries (*do, is, has*)	He **does** baking me a birthday cake
	modals (*can, must, will …*)	She **is** speak 11 languages!!
	third singular	Todd sign**ed/es** fluently now.
TENSE	regular past	The cop killed**ed** the burglar.
AGRO	regular past participle	Joe has talk**en** too long.
	irregular past participle	Jeff has **saw** this before.
	progressive	Todd is **gone** to class
	infinitive	John will probably **writes** a paper

8. Results

Before turning to a more detailed presentation of our results, there are some general findings we would like to mention taking the population as a whole into consideration: 30 left hemispherectomies, 20 right hemispherectomies. First, it is important to keep in mind that the subjects included in our present analysis comprise only a subset of the children in the study. Second, almost all of our subjects who have undergone hemispherectomy have experienced delays in the onset of speech. This delay is not unexpected, given that both seizure activity and neurological abnormalities between seizures interferes with normal neurological and cognitive development.

Third, surprisingly, there is a higher proportion of right hemispherectomies in the overall subject group who have no language than left hemispherectomies. Five of the 20 right hemispherectomies, or 1/4 of the 18 right hemispherectomies who are 3 years or older, have no language, while only 5 of the 30 or 1/6 of the left hemispherectomies 3 years or older have no language. Fourth, 4 of the 13 children who had left hemispherectomy at or after the age of 4 are fluent speakers according to our data, and 4 additional children from this group of 13 are reported by their parents to be fluent. If true, this would constitute close to 2/3 of the sample who had surgery near the end of or after the active language acquisition years whose right hemispheres have constructed rich grammars.

Turning now to the group of children whose language sample data we have included in our analysis, we see that our specific findings, which are summarized in Table 2, are more in line with our predictions.

Table 2: % Error for the I-system categories per child

	child	subj. pron.	aux/ mod.	-ed	-d	-s	to	-en	-n	-ing
left	**LB**	0	0	0*	0	0*	0	-	0	0
	GD	3.6	8.3	12.5	9.1	8.33	5.6	0	20*	0
	JF	33.3	-	-	-	-	-	-	-	0
	JB	62.5	28.6	0	-	-	0	-	100*	0
	GG	0	33.3	100	57.1	-	0	-	0*	-
	SM	2	43.8	0*	-	66.7	-	-	0	25
	RP	-	100*	-	-	-	100*	-	-	0
	MW	33.3	0	-	-	0*	100*	-	-	-
mean error %		**19.2**	**30.6**	**22.5**	**22**	**18.8**	**34.3**	**0**	**24**	**4.16**
right	**SL**	1.47	3.57	4.35	0	0	0	0	4.76	0
	MC	0	0	0	0	25	0	0	0	0
	JE	0	0	0	-	-	0	-	-	0
	BB	0	1.2	12.5	3.9	0	0	0	-	0
	MO	1.3	1.9	33.3	5.6	7.1	0	0*	-	0
mean error %		**0.6**	**1.4**	**10**	**2.4**	**8**	**0**	**0**	**2.38**	**0**

subj. pron. = subject pronoun
aux/mod. = auxiliary / modal
-ed = regular past
-d = irregular past
* = out of 1 occurrence
-s = 3rd person singular
to = infinitival *to*
-en = regular past participle
-n = irregular past participle
-ing = progressive or present participle

First, as can be seen in Table 2, our first hypothesis is borne out. There is a clear difference in the range and incidence of I-system structures used by the two groups, with the right hemispherectomies utilizing a greater range and number of I-system elements almost across-the-board. Comparing the mean rates of error between the left- and the right-hemispherectomies on *individual* I-structures the differences turned out to be *not* statistically significant. However, in each case the difference was in the predicted direction, which in itself can constitute evidence of the real differences between the groups. On the other hand, a between groups comparison for the set of I-structures as a *whole* did reach statistic significance at a level of $p < .05$ by a Chi-square test. The variability among the left hemisphere subjects is a matter we will take up in a few moments.

Some illustrations of I-system errors in both left- and right-hemispherectomied children are given in (7) on the hand-out:

(7) *Left hemispherectomied*

a. he __ big (SM)
d. where __ the picture? (SM)
b. *me* go home (SM)
c. he say__ woof woof (SM)
e. me and my mom like __ play ball (SM)
f. he went to sleep and then he *wake* up (GG)
g. ... and then he *run* and *run* (GG)
h. I dream of *to stay* up (GG)
i. and then they *be* all done (past context) (GG)
j. I _ not tell a story (GG)

Right hemispherectomied

k. I am sleep_ on the floor (MO)
l. you know first I hadd*ed* the Indian hat? (MO)
m. I got a card with this guy on it and he say_ "Yabba Dabba Doo" (MO)

Certain I-structures showed the clearest discrepancies between the two hemispherectomy groups. In contrast with the frequent, almost error-free use by the right hemispherectomies, the left hemispherectomies showed considerable problems with auxiliaries. With one exception (LB), when auxiliaries occurred with any frequency in obligatory contexts, the error rate was markedly higher among the left hemispherectomied children. Unexpectedly, alongside the high omission rate of auxiliaries, two of the left hemispherectomies, SM and GG, utilized correct nominative case pronouns in subject position. This is surprising in light of our theoretical assumption that nominative case is checked in AGRSP, whose head hosts auxiliaries. Thus, if the auxiliary is missing, there is no element in AGRS against which nominative case on the subject can be checked.

Our second hypothesis, that the right hemispherectomies would exhibit normal developmental patterns with respect to the I-system, eventually attaining the adult I-system of the target language is only partly supported. The group error rates on certain structures, namely regular past tense and 3rd person sg. -s, appear higher than would be expected in a normal, mature sample. We note, however, that although BB (3;5) and MO (5;11) both showed clear delay in speech onset and have not yet achieved an adult grammar, since the onset of speech they have shown consistent linguistic growth and normal developmental patterns.

Our third hypothesis, that the grammars of left hemispherectomy children will embody instantiations of I present in adult English, is also supported. Every child in the left hemispherectomy group except one, who we will discuss in a moment, used at least some correct I-system structures.

9. Discussion

Despite the greater error rates in the left hemispherectomy group than the right hemispherectomies, 2 of the 8 left hemispherectomies are striking exceptions, namely the first and the second one in Table 2: LB and GD. LB, who had surgery at the age of 9;6, could have been expected to have a very poor linguistic outcome given her advanced age at surgery. However, through Wada testing, she is known to have had right hemisphere language before surgery, and this fact accounts for her almost adultlike speech at the age of 10;8.

In contrast, GD, who had surgery at the age of 1;5, truly diverges from the expected outcome. She had no language prior to surgery, yet at age 4;5, despite left hemispherectomy, has a grammar very close to the target grammar. However, her language is not entirely normal and is the subject of a case study in preparation. Her speech contains lexical errors and is filled with false starts, but, as mentioned before, her grammatical development does not seem to be impaired. In (8) we give a few examples of her speech.

(8) *False starts*
- a. and then, and then I can go to, I can go home and tell my momma I have a, my, baby
- b. I'm going in, I'm gonna go in a party after Daddy put-es a pony tail in my hair
- c. she, she, she's our baby sister, she's our, my, she's my babysitter, but she's my sister

Non-impaired syntax
- d. I want Daddy to stay with me
- e. I called my mommy on the phone
- f. I want to go home to ... Kentucky, when I'm done talking to these doctors
- g. do, do you like my shoes?
- h. these are bigger ones

There are two other left hemispherectomy children in our series whose data have not yet been analyzed, but whose language is reported to be fluent and adultlike. Each of these children had surgery at approximately the same age as GD and all are currently the same age. All three are now seizure-free.

Contrast this pattern of linguistic growth with that of RP, who had a left hemispherectomy at the same age as GD and is close to GD in age.

Unlike GD, RP has not become seizure free, implying that his right hemisphere is not damage-free and that his right hemisphere's underlying capacity is therefore compromised. RP produces only 2 contexts for I in his language sample, which consists almost entirely of NPs. GD, who has no sign of right hemisphere damage is thus a better example of how well the right hemisphere can subserve grammatical development.

Thus, those who are exceptions to our first hypothesis provide us with the clearest support for our third hypothesis - that left hemispherectomied children will develop grammars which embody instances of I present in adult English. At least some of the functional categories of I are present in the speech of all of the left hemispherectomied children except RP, even in the speech of other children whose seizures have not been completely controlled.

10. Summary and conclusion

In summary, our finding of a consistently greater rate of I-system errors in the group of left hemispherectomies suppports the view that there is a predisposition for left hemisphere specialization for grammar and its development. However, looking at individual cases we find evidence that the young brain is malleable enough to reconstitute the neural substrate for grammar in circumstances which would otherwise prevent its development. Further research is necessary to understand why some children with left hemispherectomies develop language so much more normally than others, even though the right hemisphere is the neural substrate in each of these cases. The presence of at least some I-system structures in the speech of all of the children except RP provides persuasive evidence that the human language faculty and its development is highly constrained, such that both child and adult grammars are consistently characterized by quite specific grammatical (UG) principles, instantiated in quite specific structures.

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