PRELINGUISTIC PRIMITIVES AND THE EVOLUTION OF ARGUMENT STRUCTURE: EVIDENCE FROM SPECIFIC LANGUAGE IMPAIRMENT

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Abstract
Recent research in the evolution of language has focused on a search for prelinguistic cognitive abilities which may have been co-opted by the emerging language faculty. One recent suggestion is that subitizing, or the primate and infant human ability to identify and keep track of small sets of participants without counting, may have played a role in the evolution of syntax (Hurford in press, Hauser et al 2000). If this is indeed the case, we may expect to find populations with linked impairments both in the processing of syntactic argument structure and their ability to subitize. This paper reports the results of a pilot study which seeks to test this hypothesis. A small cohort of children diagnosed with Specific Language Impairment and showing syntactic deficits were tested for their ability to subitize. The results for the group as a whole were inconclusive, but one of the subjects showed marked difficulties with both the syntactic and subitizing tasks. We conclude that while further experiments are needed with a larger subject pool, the initial results may support a neural (and therefore evolutionary) link between the processing of argument structure and the ability to subitize.

1. Introduction
Hurford (in press) lists several cognitive abilities which may have been preadaptations for language in our hominid ancestors. These features, present today in a range of species other than our own, could have been co-opted by the emerging language faculty during the evolution of modern modules for phonology, syntax, pragmatics, etc. These prelinguistic skills include:

- Phonetic/phonological: the ability to imitate/produce a wide range of sounds and discriminate between sounds
- Semantic: the ability to conceptualise and calculate
- Symbolic: the ability to link an arbitrary symbol with a concept
- Syntactic: the ability to organise sequences of sounds or gestures
- Pragmatic: social cooperation, Theory of Mind, joint attention

It is extremely difficult to collect direct evidence about evolutionary events that might have taken place hundreds of thousands of years ago, so hypotheses about preadaptations have to be tested indirectly. One useful source of evidence comes from cognitive and linguistic impairments. For example, modern human languages contain pragmatic systems, such as Grice's Maxims for conversation and a system of personal pronouns for deictic reference. If the development of Theory of Mind in the early hominid brain was a preadaptation for pragmatics, and an underlying neural link exists between the linguistic ability and the non-linguistic ability, then we might expect to find populations with impairments in both abilities. Autistic spectrum disorders provide just this kind of neurological evidence: children and adults diagnosed with these disorders tend to fail tests designed to assess Theory of Mind, and their discourse is characterised by serious pragmatic problems associated with

Nelson, D. (ed.) *Leeds Working Papers in Linguistics and Phonetics* 9 (2002), pp. 131-140.

violations of Grice's Maxims and misuse of personal pronouns. Although the exact causal relationship between Theory of Mind and linguistic deficits in autism and Asperger's remains a question of debate, many researchers believe that there is a link (Farrar & Maag, 2002). This link lends support to the idea that Theory of Mind may have been a prelinguistic evolutionary precursor to the linguistic module of pragmatics. Our hypothesis is that certain fundamental aspects of syntax, specifically the processing of core argument structure, has an evolutionary basis in an older, prelinguistic ability of primates to identify and keep track of small numbers of participants in a simple scene.

1.1 Argument arrays in natural language syntax

Before discussing the preadaptive skills in question, we need to define what we mean by *syntax*. At its most basic, syntax may be seen as a system of rules for building linguistic structures which map onto conceptual structure (Jackendoff, 1997). Natural language syntax also provides a mechanism for assigning thematic roles and linking those roles to arguments; syntactic processes (question formation, passives, clefts, etc) can then operate on linguistic structures without altering the thematic relations of the core predicate (Chomsky 1981). This allows users of a language to keep track of who is doing what to who in a given predicate across a wide range of possible sentence types. In order to interpret a predicate, then, a language user must be able to calculate the number of participants in an argument array and then keep track of those participants:

a. Harry handed the broom to Hermione.
AGENT THEME GOAL

b. Hermione was handed the broom by Harry.
GOAL THEME AGENT

c. Who did Harry hand the broom to [gap]?
OP_i AGENT THEME $GOAL_i$

As Hurford (in press) points out, core predicates in natural language range over small sets of argument arrays consisting of no more than 3 or 4 arguments. Interestingly, the limits to these "small arrays" turn up again and again in natural language grammars. First of all, grammatical number is limited to about three or four. While languages commonly encode singular, plural, and possibly dual number, there are languages which mark grammatical number for three (trial) and possibly four (quadral). Corbett (2000) argues that quadral number is best described as a type of paucal number, but this analysis is still consistent with the general pattern, as paucal typically marks small groups of about three or four. Significantly, no attested language grammatically encodes number for five people or objects.

A related "ceiling" is found in numeral systems. Many languages contain distinct sets of numerals, usually continuous, which are morphologically or syntactically distinct from the rest of the numeral set. For instance, Icelandic numerals from one to four inflect fully for case and gender, while numerals five and above are indeclinable. However, these "special sets" of numerals are nearly always at the low end of the numeral set, and almost universally within the range of 1-4 (Hurford 2002; see Nelson & Toivonen 2003 for discussion and a counterexample).

Finally, lexical verbs[1] select a maximum of four arguments. Transitive verbs take two arguments, ditransitive verbs take three, and a very small handful of lexical verbs are "tritransitive" and take four arguments (for example BET in *I bet Bob a pound that Estonia will win the Eurovision Song Contest*). This restriction begs an explanation, since it is relatively easy to conceptualise a scene or event containing five, fifteen or fifty participants. Natural language, however, restricts the set of arguments selected by a lexical verb to four.

In human grammars, then, there seems to be a special significance attached to small arrays containing a maximum of three or four participants. In the next section, the relevance of this for language evolution will be addressed.

1.2 Evolutionary Precursors to Syntax

The ability to identify, interpret and keep track of small sets of arguments in an array is a crucial human ability, but what are the evolutionary origins of these abilities? Hurford (in press) argues that predication in natural language does have evolutionary precursors in the ability of animals to apprehend objects in the world and describe properties to them. Structures exist in the brain in the dorsal pathway ("what") which attributes properties to objects, and the ventral pathway ("where") which locates objects in space. Research has shown that both primates and humans share these two independent pathways which are associated with visual and auditory processing of information. Hurford arguesthat these pathways may have been neural preadaptations for language that were later co-opted by the emerging language faculty. Most relevant for the current study is the *number* of objects that can identified by these structures in the brain at any one time. Experimental evidence shows that animals and human infants can only keep track of a small array of three or four objects at a time. In this section, evidence from cognitive science for the significance of small arrays is presented.

In the animal kingdom, certain animals have been found to be able to calculate numerosity for small numbers of objects. Without special training, rhesus monkeys can discriminate between sets of 2 and 3 objects (in this case apple slices), 2 and 4 objects, and 3 and 4 objects, but not between 4 objects and 5, 4 and 6, 5 and 6, and so on (Hauser, Carey and Hauser 2000). This suggests that monkeys can keep track of up to four objects, but not more. Similar results have emerged in experiments with African Grey Parrots (Pepperberg 1987) and chimpanzees (Boysen & Berntson 1989).

Human infants also share a similar ability to discriminate between small sets of objects. In infant gaze experiments, very young babies look longer at a screen when 2 objects are replaced by 3, or 3 by 4, but not when 4 objects are replaced by 5 and so on (Wynn 1995).

The evidence from cognitive science suggests that children and adults can calculate numerosity for sets of objects in two different ways. Past a certain stage of cognitive development, children can use linguistic symbols (numerals) to count[2] objects, and in this way calculate a theoretically infinite number of objects. But children and adults also have the ability to *subitize* when they calculate small sets of objects at a glance. Experiments have shown that young children can subitize at 200ms (and adults much faster), and that this ability definitely precedes the ability to count (Starkey & Cooper 1995). Moreover, the subitizing range for both children and adults is around 4 objects (Pylyshyn 1989). This means that within a fraction of a

[1] By lexical we mean core lexical, without augmentation by for example causative morphology or light verbs.

[2] This ability does not include 'mental arithmetic'.

second, children and adults can calculate numerosity for sets of up to about 4 objects, but this ability to subitize breaks down for larger sets of objects, which must be counted. Additional evidence that subitizing is distinct from counting comes from the domain of neurological impairments. The ability to subitize may be selectively impaired while the ability to count is spared (developmental and acquired acalculia, Butterworth 1999).

The evidence from cognitive science, then, shows that higher animals, human infants and human adults all share a capacity to apprehend up to about 4 objects at a time without special training. This capacity appears to be embedded in natural language grammars, which appear designed to handle small sets of participants without the necessity of "counting". The fact that the ability to subitize appears to cross species barriers suggests that it may in fact be a neural preadaptation for language (Hauser et al 2000, Hurford in press). As neural architecture for syntax evolved in the early hominid brain, pre-existing structures already in place for identifying and attributing properties to small arrays of objects may have been co-opted for a role in syntactic processing.

The question is, how can this hypothesis be tested? If there is any evolutionary link between the ability to subitize and the ability to process argument arrays in syntax, then there may be a residual neural link in the modern human brain. One way to investigate this is to look at populations with an impairment in one of these domains, and then test their ability in the other domain. One such population is children diagnosed with Specific Language Impairment (SLI), who tend to do poorly on tests designed to handle their ability to process argument structure (Van der Lely 1997). Anecdotal evidence from speech and language therapists suggests that children with Specific Language Impairment (SLI) do indeed have problems subitizing. But what is SLI?

2. Specific Language Impairment (SLI)

Children with SLI are characterised as having problems in the development of language comprehension and/or production, but not showing impairment in their non-linguistic cognitive or motor development, hearing or emotional-social behaviour. In addition, there is a genetic component to this disorder (Bishop, North and Donlan, 1995). Recently, Fisher, Vargha-Khadem, Watkins, Monaco and Pembrey (1998) have identified a region on chromosome 7 which co-segregates with the speech and language disorder, confirming autosomal dominant inheritance. The genetic basis of SLI has also been supported by a recent paper by Lai et al., (2001) who on the basis of investigations on a three generation family, KE, with speech and language difficulties, and one unrelated individual CS, show that the gene FOXP2 is involved in the developmental process that culminates in speech and language.

SLI is a spectrum and several subgroups of children with SLI have been identified (Conti-Ramsden and Botting, 1999): 1) children with a lexical-syntactic deficit, 2) children with verbal dyspraxia, 3) children with phonological programming deficit syndrome, 4) children with phonological-syntactic deficit syndrome, and 5) children with semantic-pragmatic deficit syndrome. Van der Lely and colleagues (Van der Lely, 1994, 1997 a, b; Van der Lely & Stollwerck, 1996; Van der Lely, Rosen and McClelland, 1998) have argued that there exists a subset of children who have severe difficulties with the computational syntactic system, referred to as Grammatical SLI children (G-SLI). The most prominent characteristic of Grammatical SLI children is an impairment in inflexional morphology and complex syntax. These children have been reported to have difficulties with the following:

- omissions of 3rd pers. sing, -*s* and noun plural -*s* (Rice and Oetting, 1993);
- errors with regular and irregular past tense (Gopnik & Crago, 1991, Ullman & Gopnik, 1999);
- overregularisation errors at age 9-12, when such errors are not expected. Overregularisation of the past tense morpheme for instance has been documented by Eyer & Leonard (1994, 1995), Leonard, Bortolini, Caselli, McGregor, and Sabbadini (1992).
- when asked for grammatical judgements in comprehension tasks, they accept forms like ***falled*** or ***walk*** with past reference as correct (Van der Lely and Ullman, 1996).

Problems with syntax when no semantic/pragmatic cues are available as the following studies have shown:

- Reversible passives, e.g. '*The dog is bitten by the girl*'. When asked to assign the role of agent and patient, they tend to assign *the dog* the role of an agent, simply because that is semantically more plausible, ignoring the sentence's underlying syntax (Bishop, 1982; Van der Lely, 1994);
- Intrasentential assignment of reference to anaphors and pronouns as characterised by the Binding Theory (part of the Government and Binding Framework, Chomsky, 1981) was investigated by Van der Lely and Stollwerck (1997).
- Argument structure (Van der Lely 1997). Children with SLI have been shown to have problems with verbs requiring more than 2 arguments and they often tend to omit an obligatory argument with verbs such as *give*.

If there is any evolutionary link between the ability to subitise and the ability to process argument arrays in syntax, then there may be a residual neural link in the modern human brain. One way to investigate this possible link is to look for populations with an impairment in one of these domains, and then test their ability in the other domain. As described in the previous section, children with SLI may be one such population. Therefore the aim of the present paper are:

a) To investigate if children with SLI show linked impairments in their ability to process argument structure and their ability to subitize. If Hurford's hypothesis is true and if there is an evolutionary link between the ability to subitise and the ability to process argument structure, one would expect that individuals with SLI who have difficulties with processing argument structure would also struggle with subitising.
b) To look for evidence in SLI children for a dissociation in their ability to subitize versus their ability to count objects. If subitising is a separate ability from counting and a preadaptation for processing argument arrays in human syntax, then we would expect that those individuals who have difficulty with subitising will not have difficulty with counting.

3. Experimental design

3.1 Participants

The study included 4 children (3 males, 1 female) aged 9-11 (mean age 10;05). They were all diagnosed with Specific Language Impairment by a speech and language therapist and are currently attending a special school for children with speech and language difficulties. All children scored at least one standard deviation below the mean on standardised language tests. The children had no known emotional and psychological problems nor cognitive deficits. All 4 participants were tested for non-verbal skills using the Coloured Progressive Matrices (CPM) (Raven, 1982) and their score are presented in Table 1:

Child's initial	Coloured Progressive Matrices (centile)
B	10^{th} -25^{th} centile
T	75^{th} –90^{th} centile
G	10^{th} –25^{th} centile
C	10^{th} - 25^{th} centile

Table 1: participants' performance on the CPM

Child B, G, and C scored in the range between 10th and 25 centile, and child T scored between 75th and 90th centile (average range is between 25^{th} – 75^{th} centile).

3.2 Tasks

Our experiments were designed to investigate a potential link between the ability to subitise and the ability to process verb argument structure. In order to rule out the possibility that children with SLI have problems with number in general, tests were also designed to evaluate the childrens'ability to count objects.

All the participants were given 4 tasks: 2 involving verbal and 2 involving non-verbal stimuli. The details of the tasks are presented below:

Tasks involving verbal stimuli:

Task 1: The first verbal task was a picture-matching task consisting of 18 sentences, 6 each representing 1, 2 and 3-argument predicates (a full list of verbs is provided in Appendix 1). 2- and 3-argument predicates were semantically reversible. The child was read one sentence at a time and asked to point to the picture corresponding to the sentence.

Task 2: The second task was a grammaticality judgement task consisting of 20 sentences, all containing verbs with a minimum of 3 arguments (GIVE, PUT, BORROW, SHOW, LEND, TAKE, GET, BET, MOVE, BUY FOR, THROW AT). 10 sentences were ungrammatical (missing an argument or containing an extra argument) (a full list is available in Appendix 1). The child was asked to say whether the sentence sounded OK or whether it sounded bad.

Tasks involving non-verbal stimuli:

The participants were presented with 2 tasks for which the stimuli were non-verbal:

Task 3: This was a counting task using arrays of 3-9 coloured objects and the child was asked to count how many objects there were.

Task 4: The second task was a subitizing task, in which 20 arrays of 2-5 coloured objects were displayed for approx. 500ms only once in a randomised orderThe children were asked to say how many they saw. The arrays were presented at regular intervals of 3 seconds.

All the participants were tested in a quiet room with only the two researchers present. The sessions were video-recorded.

4. Results

4.1 Picture-matching task

The results from the two tasks involving verbal stimuli (1 and 2) are presented in Table 2 respectively.

	1-argument	2-argument	3-argument
B	100	100	83.3
T	100	100	66.7
G	100	100	66.7
C	100	100	50.0

Table 2: Results from the Picture Matching Task

Table 2 shows that all four participants with SLI had no difficulties with 1 and 2-argument structure verbs, however they all had problems with the 3-argument structure verbs. One participant, child C, was correct only 45 percent of the time, participants T and G were correct 60 percent of the time, whereas T was correct approximately 80 percent of the time.

4.2 Grammaticality judgement task

The results of the second task involving verbal stimuli are presented in Table 3.

	Grammaticality judgements% correct
B	60
T	95
G	90
C	75

Table 3: Results from the Grammaticality Judgement Task

As Table 3 shows, all the participants experienced difficulties with the Grammaticality Judgements task, their performance ranging from 60% correct for participant B, 75% correct for participant C, 90% correct for participant G and 95% correct for participant T.

4.3 Counting

All participants scored at ceiling in this test and were able to count up to nine objects.

4.4 Subitizing

The results from the subitizing task are presented in Table 4.

Child’s initial	2 objects	3 objects	4 objects	5 objects
B	100	100	100	100
T	100	100	100	100
G	100	100	100	80
C	100	60	80	40

Table 4: Results from the subitizing task

As Table 4 shows, two participants (B and T) performed at ceiling for this task scoring 100% correct; one participant (G) had difficulty subitizing above the 1-4 range, and the fourth participant (C) had difficulty subitizing more than two objects.

5. Discussion

The aim of the above experiments was twofold: to investigate whether SLI offers evidence for the hypothesised proposal that the ability to subitize in humans may be a possible underlying mechanism for natural language predication; and secondly to investigate whether there is a dissociation of the ability to count and the ability to subitise in individuals with SLI.

The results confirmed some of the previous findings that children with SLI have difficulties with argument structure. On the picture matching task, all the participants with SLI had some problems with the 3-argument verbs, though they all scored at ceiling levels for the 1 and 2-argument verbs. The participants scored better on average on the Grammaticality judgement task, although never at ceiling levels.

With regard to the first aim of the paper, i.e. whether SLI may offer evidence for a possible link between the ability to subitise in humans and their ability to process argument stucture, the results of the present study are inconclusive; however they do not completely dismiss the hypothesis for a possible link. One of the participants (child C) had substantial problems with argument structure for verbs requiring more than 2 arguments and also had considerable difficulties with subitising more than two objects. For the remaining three participants the results were not clear. This finding warrants further investigation with a larger data sample than the present one.

Regarding the second aim of the paper, the results showed that all the participants could definitely count; however they were not all very successful at subitizing, especially when the number of objects was above 2. Thus even though this was not the case with all the participants' the fact that one participant (C) had serious problemswith the subitising task although she was able to count, and another participant (G) though marginally, also had difficulties subitising although he was able to count. This supports previous hypotheses that the ability to count and the ability to subitise may represent two distinct skills subserved by different brain mechanisms (Simon 1999, Butterworth 1999, etc).

6. Future Research

The results from the present study are inconclusive though indicative of the fact that the ability to subitise in humans may have been an evolutionary preadaptation for the development of predicate-argument structure in human language. The results in the present study may have been confounded by the fact that the subitizing task was based on a timing of 500ms. This could have made the task easier and may have been the reason why two out of the four children did not have any difficulties with it. Therefore future experiments need to use a much shorter time interval, i.e. 200ms.

If a link between subitizing and argument structure is to be postulated, then the reverse should hold: i.e. individuals with developmental acalculia who are known to have problems with subitising (Butterworth, 1999) should have problems with argument structure. Therefore further research in needed which will not only involve participants with SLI but also participants with developmental acalculia. Furthermore, there are ndividuals with WS who have very good language abilities especially within the domain of syntax (Clahsen and Almazan, 1998; Bellugi et al, 2000). If subitising is a separate cognitive skills from other cognitive skills then we should expect individuals with WS who have no difficulties with predicate-argument structure to be able to subitize.

And an obvious limitation to the present pilot study is the absence of a matched control group, which makes the results of the present study rather tentative. This will be need to be taken into consideration any in future research of this kind.

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