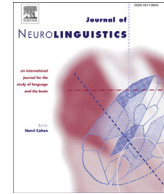




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Neural basis for processing hidden complexity indexed by small and finite clauses in Mandarin Chinese



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ABSTRACT

In this study we investigate how the human brain processes small clauses and finite clauses. Small clauses are instances of ‘simpler’ syntax in the sense that they do not involve operations such as Move and Tense, and have been argued to represent an earlier stage of syntactic evolution before the development of fully-fledged syntax (Bickerton, 1990; Jackendoff 2010; Uriagereka, 2008). Understanding how the brain processes instances of different levels of syntactic complexity may further our understanding of (i) the analytical functions of specific brain regions, and (ii) the distribution of labor in the interpretation or different levels of syntax. To pursue this hypothesis, we ask whether small clauses require different analytical processes than regular syntax. This report provides evidence that they do. In an fMRI study of syntactic processing in a group of Mandarin speakers, small clauses showed greater activation of areas involved in semantic processing. In addition, both small and finite clauses showed substantial activation of areas implicated in syntactic and semantic processing, including significant RH activation.

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We interpret these findings with reference to Levinson's articulatory bottleneck: structures which appear simpler in terms of syntactic production may require more effort in parsing.

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1. Introduction

In the growing field of evolutionary linguistics, one fundamental question regarding the human language faculty is whether it evolved gradually or not. While Chomsky and the Minimalist school suggest that syntax is too abstract for gradual adaptive evolution, Darwinian approaches would argue in favor of such gradual evolution. Indeed even within Minimalist Syntax scholars such as Progovac argue for a gradual evolution of grammar (Progovac, 2010).

While a sudden mutation as the one implied in Chomsky's approach is difficult to prove or disprove, gradual theories of evolution can be tested. In evolutionary approaches to language a useful concept to discuss the type of evolution that might have led to modern language is the notion of proto-syntax (Bickerton, 1990; Hurford, 2012; Jackendoff, 1999, 2002, 2010). In this view we envisage a series of different stages of evolution which include a purely symbolic phase, a phonetic phase and then, immediately preceding the development of hierarchical phrase structure, a proto-linguistic phase (Jackendoff, 1999, 2002, 2010). The proto-linguistic phase – or proto-syntax – can be identified by a number of linguistic 'fossils', i.e. properties of proto-syntax that still survive in modern languages. These fossils are universal in language and behave in particular ways: in particular they emerge early on in language development and they are retained in aphasia, suggesting that they might trigger a different kind of processing from fully-fledged syntax. They include formulaic speech, Noun–Noun compounds as well as adverbial and prepositional phrases, in other words phrases where semantic relationship is established by linear order only and not signaled by any higher order hierarchical structure. A type of structure that has been categorized as proto-syntax is the small clause. Small clauses are simply put argument-predicate constructions, such as 'Mary angry' that allegedly existed before Merge, Move and Tense and as such may belong to an 'older' stage of the language faculty (Progovac, 2010; Uriagereka, 2008).

In this study we test whether small clauses are processed differently in the human brain from non-finite clauses. If small clauses are indeed part of proto-syntax and represent an earlier stage in the evolution of human language, we might expect to find a difference in the way in which they are processed. In particular, we aim to uncover (a) whether small clauses are processed in different areas of the brain from finite clauses, and (b) whether they require more or less processing than finite clauses. The answers to these questions bear significance for our understanding of linguistic complexity.

How linguistic complexity should be defined is a central issue in linguistics and holds the key to a major aspect of the study of language. If language is indeed a biological trait of humans, as argued by Chomsky and the generative school, then languages must be of approximately equal complexity (or simplicity) overall, even if they may differ in the complexity of sub-domains of grammar (say morphology vs. syntax). If on the other hand language is part of human culture, different languages could show different degrees of complexity, related to the complexity of the cultural system in which they evolve. The presence of morpho-syntactic processes is often linked to higher complexity, while their absence is typically seen as an instance of simplicity. But this only relates to the production side of language. What about processing? Is there a direct or an inverse correlation between complexity in production and processing?

We first briefly review what is known about the neural basis of syntactic processes (see Fedorenko, Nieto-Castañón, & Kanwisher, 2012). A number of brain regions have been found to play a role in syntactic processing. The first and most influential one is Broca's area, defined as including the opercular and triangular portions of the left inferior frontal gyrus, IFG. Carramazza and Zurif (1976) showed the difficulties encountered by agrammatic aphasics when interpreting structures where the order of the noun phrases does not correspond to the order of thematic roles. Regions around this area

systematically show to be heavily involved in complex syntactic processing in several studies; at the same time, areas in IFG are also involved in lexical and phonological processing. Another area involved in syntactic processing is the posterior superior temporal gyrus/sulcus, STG/STS (see e.g. [Grodzinsky & Friederici, 2006](#)), though non-syntactic types of processing also occur in this area. A third region that serves what appear to be both syntactic as well as non-syntactic processing is the left anterior temporal lobe (ATL). This area has interestingly also been identified as one of the meaning centers in the brain ([Pulvermüller, 2010](#)). In particular the anterior part of the superior-temporal gyrus has been shown to be heavily involved in semantic processing ([Patterson, Nestor, & Rogers, 2007](#)), while the temporal lobe seems to play a key role as lexical interface between phonology and semantics ([Hickok & Poeppel, 2007](#)). This of course does not exclude other regions of the brain from being potentially involved in semantic processing. As noted in various studies, so far no brain region has been found to be exclusively engaged in one specific linguistic process alone (see [Fedorenko et al. 2012:188](#); [Pulvermüller, 2010:257](#)).

One interesting difference worth noting is that, while syntactic processing appears rather lateralized, semantic circuits seem to be spread more evenly across both hemispheres. [Kahlaoui, Scherer, and Joannette \(2008\)](#) review the evidence for RH involvement in semantic processing, and find that both behavioral and neuroimaging studies show convincing evidence of RH involvement in semantic processing. Behavioral studies show that while both LH and RH access the lexicon, RH-based networks have a heavier involvement in accessing semantic categories. Especially semantic priming seems confined to RH (see [Chiarello, Burgess, Richards, & Pollock, 1990](#); [Chiarello & Richards, 1992](#)). In contrast to LH, RH employs coarser semantic coding, keeps multiple meanings activated and shows a broader activation ([Beeman et al. 1994](#); [Koivisto, 1997](#)). Neuroimaging studies further show RH involvement in particular in postlexical semantic matching ([Koivisto & Laine, 2000](#)). Lexical ambiguity and semantic integration tasks activate in particular areas such as right anterior cingulate cortex, right superior temporal gyrus, and right middle temporal sulcus. Crucially, it seems that RH involvement increases as semantic complexity grows ([Jung-Beeman, 2005](#)). Related to this is the observation that the closer to natural language experimental conditions get, the more activation is seen in the RH ([Xu, Kemeny, Park, Frattali, & Braun, 2005](#)). It is safe to say that, while syntactic processing seems to be heavily lateralized in LH, semantic processing requires cooperation between LH and RH and that complex semantic tasks require heavy RH involvement. The significance of RH in semantic processing is further corroborated by studies of patients with brain lesions. It is clear from these studies that RH-damaged individuals struggle to access semantic categories, fail to draw inferences and do not fully use contextual clues ([Kahlaoui et al. 2008: 559](#)).

[Bisang \(2009\)](#) introduces an approach to the study of linguistic complexity in which the role of syntax and semantics respectively are reconciled. While theoretical approaches to the study of structure have tended to favor a focus on the presence vs. absence of morphological material, Bisang argues that we must not lose sight of a hidden type of complexity, namely the inferential or semantic one. This idea is based on the notion of ‘articulatory bottleneck’ developed in [Levinson \(2000\)](#): the phonetic actualization of a planned encoded message is around four times slower than the pre-articulatory process of encoding itself, and in ordinary linguistic communicative situations speakers often opt for economy rather than overt explicitness and precision to attain communicative efficiency. Any utterance is expected to be interpreted fully by a hearer through such heuristics as Gricean pragmatic principles, and the hearer fills the gap of what is not said. The speaker’s efficient strategy to get around the ‘bottleneck’ hence leads to varying degrees of covert complexity on top of the overt linguistic form, as a result of the competition between conflicting forces of economy and explicitness. Following this idea, languages can display different degrees of overt and hidden complexity in their grammars. Languages of East and mainland Southeast Asia are typical examples of languages which, while showing limited morpho-syntactic complexity, display a high degree of hidden complexity. Languages such as Mandarin have almost no obligatory markings of grammatical categories and a marker can be omitted if it is retrievable from the context. This suggests that such languages would impose a higher cost on the hearer in terms of inferential processes, which we take to entail more active semantic processing in the brain. In order to test this hypothesis, we investigate finite and small clauses in Mandarin: while these are structurally comparable, and thus allegedly similar in terms of overt complexity, we expect them to be semantically different, for reasons elaborated on below.

2. Methods

A ‘small clause’ (SC) is identified here as an argument-predicate combination that typically excludes clausal functional projections. It is the core of a sentence that subsequently becomes a (full) finite sentence after the Merge of, for example, Tense, and Move of the subject into the specifier of the tense phrase (TP), as proposed in Uriagereka (2008) who views structures that exist before Merge as proto-syntax. As an SC acquires Tense and then Move of the subject into the specifier of the TP it becomes a finite clause, e.g.:

- (1) *Maria stay*
- a. SC: [Maria stay] →
 - b. [will [Maria stay]] →
 - c. TP: [Maria [will <Maria> stay]]

Small clauses can be said to be morphosyntactically less complex than finite clauses in lacking tense or agreement. It is true that various recent studies have posited more abstract structural representations for the small clause (Moro, 2000; den Dikken, 2006), but none of these analyses can be taken to be definitive. As understanding deepens, it is inevitable that structural representations become more and more complex, but which analysis to admit depends ultimately on research goals. Some recent formal works, like den Dikken (2006: 60), take the small clause as ‘a subject-predicate structure lacking tense’, which in essence is no different from the traditional view of Williams (1975). Adopting this view for our purposes, it follows that small clauses are simpler in syntax (or ‘structure’) as compared to finite clauses.

Progovac (2010: 237) proposes that such formulaic constructs as SC must be a universal property of language as they are the fundamental building blocks of all modern language. If this is the case, languages such as English may involve two distinct cognitive layers: (i) an ancient system that handles proto-syntax and (ii) a more recent system that is responsible for finite syntax. Crucial to this idea is the observation that formulaic speech of the type above, i.e. proto-syntactic, may show processing by more ancient brain structures, such that survive language disorders (Code, 2005; Wray, 2002), and may be more likely to be accessed by both procedural and declarative memories (Pinker & Ullman, 2002). In relation to this, Progovac (2010: 245–6) suggests that ‘such constructs straddle the boundary between the lexicon and syntax, constituting good candidates for providing a transition from a lexical stage (without syntax) to stages with more elaborate syntax’.

If the position sketched above is correct, it is plausible to expect that small clauses might show differential processing patterns from finite clauses. In terms of complexity, one could argue that in Mandarin Chinese small clauses and finite clauses appear structurally identical. The question is: do they require different degrees of processing effort, or are they processed in essentially the same way? If small clauses in general do indeed straddle the boundary between the lexicon and syntax, we should be able to detect this in the type of cognitive activation they trigger. An identical processing pattern would suggest no difference in complexity, while a differential activation pattern would suggest that, despite the apparent superficial similarity, different degrees of processing complexity are involved.

2.1. Experiment design

In the syntactic literature a typical small clause is identified as expressing a subject-predicate relation without a finite verb (Citko, 2011), as in sentence (2):

- (2) *I consider* [_{SC} *him a fool*]

The Chinese equivalents of such structures are generally argued to be small clauses too (Tang, 1998; Wei, 2007), as in sentence (3):

- (3) 我 当 他 傻瓜
 wo dang [sc ta shagua]
 1.SG consider 3.SG fool
 ‘I consider him a fool.’

A relationship of predication holds between the noun phrases *ta* and *shagua* in (3), but without any mediating verb.¹ Small clauses thus differ from finite clauses as complements, which are not fully grammatical in a similar configuration (4):

- (4) ??我 觉得 他 傻瓜
 ??wo juede [TP ta shagua]
 1.SG think 3.SG fool
 ‘I think he is a fool.’

Such a clause is incomplete and requires a copula verb to be properly processed. According to one analysis (Tang, 2001), verbless clauses such as [*ta shagua*] in (4) are subject to a Generalized Anchoring Principle (GAP), so that (6) sounds better than (5) due to the contrastive context (one instantiation of the GAP). But small clauses themselves, as in (3), are not subject to any such constraint, and thus it makes no difference whether or not they are embedded in a contrastive context (7–8).

- (5) ??张三傻瓜
 ??Zhangsan shagua

- (6) 张三傻瓜，李四笨蛋
 Zhangsan shagua, Lisi bendan

- (7) 他当[张三傻瓜]
 Ta dang [Zhangsan shagua]

- (8) 他当[张三傻瓜，李四笨蛋]
 Ta dang [Zhangsan shagua, Lisi bendan]

The present study aimed to compare the processing of small clauses with that of finite clauses. However, such a comparison cannot be conducted directly because predicative NPs in finite complement clauses are not fully grammatical, as shown in (4) above. To circumvent this problem, we used a contrastive structure which renders the same configuration possible with both small clauses and finite clauses (Wei, 2007: 90). In sentence (9), the verb *zan* ‘praise’ selects two conjoined, contrasting small clauses as its complement:

¹ The complement of a verb such as *shuo* ‘say’ in the experiment cannot be taken as a root clause (as in He said, ‘John is a fool’). In all the stimuli that were presented there is no comma (denoting an intonation break) in between the matrix verb *shuo* ‘say’ and its complement. Thus without any such ‘prompt’ present, the subjects were highly unlikely to process the complement of saying verbs as a verbatim quote.

- (9) 张三赞[余先生高大，刘小姐娇小]

Zhangsan zan [Yu xiansheng gaoda, Liu xiaojie jiaoxiao]

PN praise Yu Mr tall Liu Miss petite

‘Zhangsan praises Mr. Yu for being tall and Miss Liu for being petite.’

In sentence (10), the verb *shuo* ‘say’ selects a finite clause:

- (10) 张三说[余先生高大，刘小姐娇小]

Zhangsan shuo [Yu xiansheng gaoda, Liu xiaojie jiaoxiao]

PN say Yu Mr tall Liu Miss petite

‘Zhangsan says that Mr Yu is tall, and Miss Liu petite.’

Note that the exact same complement clauses are used in both sets of stimuli. For example, [Yu xiansheng gaoda, Liu xiaojie jiaoxiao] is a small clause in (9) but a finite complement clause in (10). This controls for the content of the small clauses/finite clauses. Any differences in processing of the two stimuli sets should then be due to either (a) the main clause predicate themselves, or (b) the structure selected by the predicate (small clauses versus finite clauses).

Experimental stimuli were constructed in pairs such that identical words and content were used except for the verb, which takes a small clause in Type A sentences (*dang* ‘consider’ in (11)) and a finite clause in Type B (*shuo* ‘say’ in (12)). The stimuli were presented in the form of Chinese characters, which are therefore shown in the sample stimuli below.

- (11) 张三当余先生傻瓜，刘小姐聪明人。

Zhangsan dang Yu Xiansheng shagua, Liu xiaojie congming ren.

Zhangsan consider Yu Mr fool Liu Ms smart person

‘Zhangsan considers Mr Yu a fool, Ms Liu a smart person.’

- (12) 张三说余先生傻瓜，刘小姐聪明人。

Zhangsan shuo Yu Xiansheng shagua, Liu xiaojie congming ren.

Zhangsan say Yu Mr fool Liu Ms smart person

‘Zhangsan says Mr Yu is a fool, and Ms Liu a smart person.’

40 control sentences were constructed, similar in content and length (number of characters) to the experimental stimuli but without an embedded clause, as in (13).

- (13) 余先生是傻瓜，刘小姐是聪明人。

Yu Xiansheng shi shagua, Liu xiaojie shi congming ren.

Yu Mr be fool Liu Ms be smart person

‘Mr Yu is a fool, Ms Liu is a smart person’

2.2. Participants

Thirteen college students (6 males) participated in this fMRI experiment. All were native Chinese speakers, ranging in age from 20 to 29 years. They were strongly right-handed, as assessed by the handedness inventory (Snyder & Harris, 1993). They were physically healthy and free of neurological disease, head injury and psychiatric disorder. Subjects were paid for their participation and gave informed consent prior to testing. The study was approved by the Institutional Review Board of The University of Hong Kong.

2.3. Materials and design

As illustrated in the previous section, three types of stimuli were used for this study: (a) sentences with small clause-taking verbs; (b) sentences with finite clause-taking verbs; (c) control sentences in which word had a larger or smaller physical size than other words. The experimental task for conditions A and B was that the subject judged the semantic plausibility of each sentence viewed. In the control condition, subjects were required to judge whether or not all the words in a sentence had the same physical sizes.

A blocked design was used. There are 9 blocks in total, with 3 blocks in each condition. For the experimental conditions (i.e., small clause-taking verb and finite clause-taking verb), there were 5 trials in each block, with one nonsense sentence as a filler. Each sentence was displayed for 4 s, followed by a 800 ms-blank screen in each trial. For the control condition (i.e., font-size judgment), there were 8 trials in one block, and each sentence was displayed for 2s, followed by a 1s blank screen. Half of the sentences contained words all with the identical font size.

The experiment was performed on a 3 T Siemens MRI scanner at the Beijing 306 Hospital. A T2*-weighted gradient-echo echo planar imaging (EPI) sequence was used, with TE = 30 ms, TR = 2s, flip angle = 90°, field of view = 21 cm, slice thickness = 4 mm, and the image matrix = 64 × 64. Thirty axial slices were acquired to cover the whole brain. Visual stimuli were presented through a projector onto a translucent screen and subjects viewed the screen through a mirror attached to the head coil.

2.4. Data analysis

The Statistical Parametric Mapping software package (SPM8) (<http://www.fil.ion.ucl.ac.uk/spm/>) was used for pre-processing and analysis of imaging data. Functional images were realigned to remove movement artifact. They were then spatially normalized to an EPI template based on the ICBM 152 stereotactic space. An isotropic Gaussian kernel (8 mm full width at half-maximum) was applied for spatial smoothing. The first three volumes of each fMRI scan were excluded from further analysis to allow for T1 equilibration. Each time series was high-pass filtered with a cutoff period set at 128 s to remove low-frequency components. For each subject, contrast images were generated by subtracting the control condition from each of the experimental conditions. Brain regions are estimated from Talairach and Tournoux, after adjustments for differences between MNI and Talairach coordinates (Talairach & Tournoux, 1988).

3. Results

Group contrast images were created with the voxel wise threshold set at $P < 0.05$, FDR corrected for multiple comparisons and an extent threshold of 10 contiguous voxels. Direct contrast between the small clause-taking verb condition and the finite clause-taking verb was performed with the voxel wise threshold set at $P < 0.001$ uncorrected (cluster size at $P < 0.05$ FWE corrected). Brain activations related to small clause-taking verb sentences contrasted with baseline include an extensive neural network (Fig. 1), with peak activation in middle temporal gyrus, medial frontal gyrus, inferior and superior frontal gyrus, fusiform gyrus, and inferior parietal lobule. Brain activity associated with finite clause-taking verb sentences was localized to middle and superior temporal gyri, superior frontal gyrus, angular gyrus, and inferior frontal cortex (Fig. 1). Some of these cortical regions are crucial for semantic and syntactic processing of sentences, confirming that our subjects performed the experimental task well. Importantly, direct contrast between the small clause-taking verb sentences and finite clause-

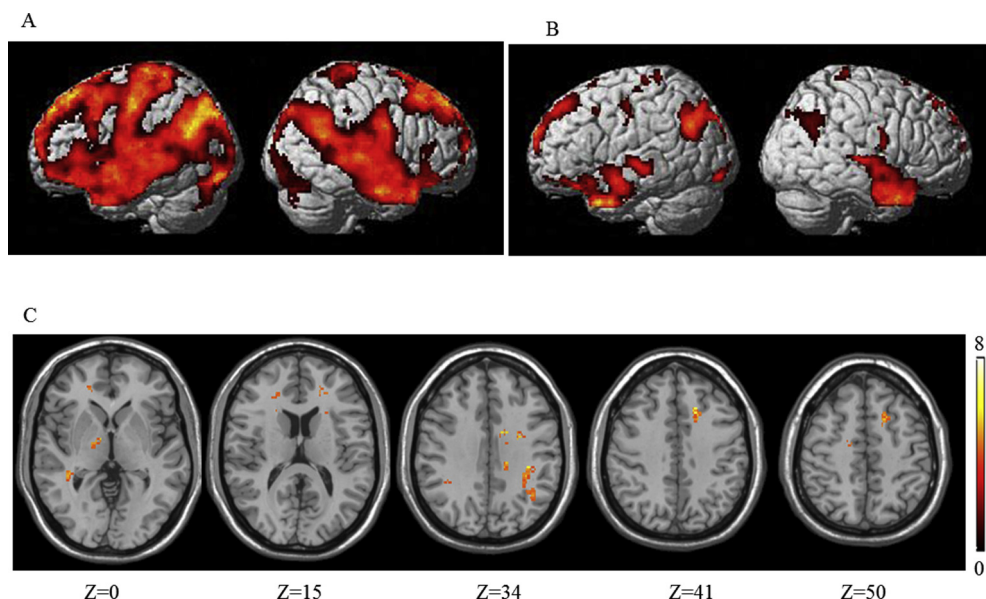


Fig. 1. Brain activations related to small clause-taking and finite clause-taking verb sentences. A: activation associated with small clause-taking verb sentences contrasted with baseline; B: activation associated with finite clause-taking verb sentences contrasted with baseline; C: direct contrast of small clause-taking and finite clause-taking verb sentences.

taking verb sentences found greater activation for small clause-taking verbs in regions including left nucleus caudate ($x = -20, y = 14, z = 16$), left middle temporal gyrus (BA21, $x = -40, y = -40, z = 0$), right supramarginal gyrus (BA39; $x = 45, y = -48, z = 34$), cingulate gyrus (BA 32; $x = 13, y = 16, z = 38$), thalamus, and SMA ($x = 10, y = 35, z = 40$) (Table 1).

Table 1
Coordinates of activation peaks.

Small clause-taking verb vs. finite clause-taking verb						
Regions activated	BA	Coordinates			Z score	Volume
		X	Y	Z		
Frontal						
L middle frontal gyrus	8	-25	28	49	3.60	13
L superior frontal gyrus	6	-22	18	57	3.93	15
L cingulate gyrus	24/31	-13	-11	40	4.19	20
	24/32	-18	35	0	3.42	11
R cingulate gyrus	32	13	16	38	5.02	139
Temporal						
L middle temporal gyrus	21	-36	-42	-2	3.98	28
R middle temporal gyrus	39	33	-56	22	4.07	140
Parietal						
L superamarginal gyrus	40	-29	-40	24	3.71	18
R cingulate gyrus	23	13	-30	26	3.72	13
Occipital						
R lingual gyrus	18	20	-69	-2	3.92	23
Subcortical area						
Thalamus		-22	-13	15	4.08	14
		-10	-9	-3	3.88	56
		19	-29	0	3.66	11

L, left; R, right.

4. Discussion

In this fMRI study using a semantic judgment task, a number of brain regions such as the left middle temporal gyrus, medial frontal gyrus, inferior and superior frontal gyrus, fusiform gyrus, and inferior parietal lobule were found to subserve the processing of sentences with both finite clause-taking verbs and small clause-taking verbs. Crucially, the small clause-taking verbs elicited much stronger activity in left middle temporal gyrus and right supramarginal gyrus (BA39), indicating that these regions are important for sentence processing. Previous neuroimaging studies of syntax have identified the opercular and triangular portions of the left inferior frontal gyrus, the posterior superior temporal gyrus, and the left anterior temporal lobe as sites for syntactic information. Our study expands the neural network to the left middle temporal gyrus and the right supramarginal gyrus.

Regarding the hypotheses formulated in Section 1 above, we can conclude the following: (i) Small clauses do require a different kind of processing than finite clauses; (ii) the differences observed are not in terms of regions of the brain, which largely overlap in processing of both small clauses and finite clauses; (iii) the differences observed are in terms of degrees of activation. The differential activation observed in our study indicates that compared to finite clauses, small clauses trigger a significantly higher involvement of two areas in particular: (i) left middle temporal gyrus and (ii) right supramarginal gyrus. We highlight these two areas because there is reason to believe that they can be directly associated with semantic analysis. The left hemisphere in general has been regarded as a ‘meaning center’ (Pulvermüller, 2010: 245). More specifically, the middle-temporal cortex has been identified as a locus of (lexical) semantic activity (Hickok & Poeppel, 2007), and the temporal pole has been identified as a semantic processing center (Patterson et al. 2007). While activity shows significant individual variation, activation of areas implicated in semantics is overall high, as seen in Fig. 1A and B. Most crucially, Fig. 1C shows additional activation in processing small clauses relative to finite clauses; this, together with the fact that A compared to B shows stronger RH activation, leads us to conclude that small clauses require more semantic analysis than finite clauses.

This study is significant on at least two counts: (i) we have identified cortical regions, especially the left middle temporal region and the right supramarginal gyrus, for the processing of proto-syntax. These regions have not been identified in previous neuroimaging research on sentence processing. These findings may be interpreted as supporting the hypothesis that ease of production is inversely correlated with processing effort; in other words, what appears simple in syntax becomes complex in terms of semantic and/or pragmatic processing. As discussed earlier, this view relates to the ‘articulatory bottleneck’ (Levinson, 2000), the observed asymmetry between production and processing, which contributes to our theories of distribution of labor of language functions. In this sense we can conclude that small clauses, while exhibiting less overt complexity than finite clauses, seem to require wider and stronger activation of brain areas, and are thus semantically and pragmatically more complex; (ii) it adds to our ongoing understanding of the complex interaction between different brain regions in processing syntactic structure, in particular the fundamental role played by areas specialized for semantics in the interpretation of apparently simple syntactic patterns. Clearly further fMRI studies of processing of syntactic patterns have the potential to inform us on where and how language is processed in the human brain.

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