The impossible chaos: When the mind cannot eliminate language structure.

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A long-standing linguistic hypothesis holds that words sequences are assembled into complex hierarchical recursive structures, i.e. constituents, rather than being linearly organized [1,2]. Yet, a surprisingly limited amount of empirical evidence is available to demonstrate the psychological reality of constituent structures: the investigation of the subjective location of clicks heard during speech perception suggested that constituents function as perceptual units [3], whereas the investigation of sentence learning indicated that constituents represent the encoding units underlying recall processes [4]. In more recent years, neuroimaging studies have complemented this limited behavioral literature, by effectively demonstrating the neurobiological salience of the constituent structure. Studies on constituent structure have traditionally been based on testing the reaction of subjects to artificially generated linguistic stimuli [5,6]. Different experimental strategies have been employed to measure the neural correlates of syntactic processes with such stimuli: either the reaction to syntactic manipulations [7,8], or to syntactic errors [9-11], or the acquisition of syntactic rules that do or do not conform to human language universals [12-16]. Although suggestive of a neurobiological basis of constituent structure, the neuroimaging evidence collected so far is not entirely conclusive, as the existence of phrase structure was modelled somewhat a priori in the experimental paradigms, instead of being deduced in an unbiased manner as an emergent property of the data.

Here we support the neuropsychological reality of phrase structures by adopting a new methodology that is less prone to experimental biases: we asked the subjects to freely turn well-formed sequences of words into a disordered structure. The participants read printed sentences or noun phrases aloud, one at a time. All the stimuli contained 6 words, arranged in different constituent structures. Immediately after reading one stimulus, the sentence was hidden, and the subjects were instructed to repeat the same words as in the stimulus but in a different and completely arbitrary order. No constraints on the execution of this task nor any examples or other hints were provided to the subjects. Responses were considered as correct if they contained all and only the words presented in the stimulus, though arranged in a different order. An example of one stimulus and of a representative correct response is given in (1 a,b):

(1 a) Stimulus: *A thief has stolen the purses*
(1 b) Response: *Purses the a thief stolen has*

This free distortion task involves processes of parsing, coding and storage in working memory of the printed word sequence [17], recall from memory, and executive processes to monitor for word order, for the words already spoken, and for those yet to be uttered during response. We hypothesized that, in order to comply with the memory load task requirements, the participants would adopt a computationally more economical strategy than processing each word separately, namely using familiar word chunks. Word chunking is thought to occur at the stage of encoding and storage of the linguistic stimuli [18,19], determining a recall facilitation for the units thus formed [20].We therefore identified preserved word sequences as an index of persistence of phrase structure to word order distortion, by means of a metric that measured the amount of disorder and allowed us to test whether any regularities emerged from the participants' responses. A Transitional Change Index (TCI) was assigned to each Word Boundary (WB) between consecutive words in the stimulus. We scored a TCI = 1, when two adjacent words in the stimulus were placed in non-adjacent positions in the response; a TCI = 0, when adjacency was maintained, irrespective of mutual word order.

In a first experiment, in which we presented well-formed sentences in Italian, we expected a higher mean TCI proportion in WBs between constituents than in WBs within constituents, suggesting that subjects were unconsciously sensitive to the underlying phrase structure of the stimuli, and that they tended to preserve it in their responses. This experiment alone, however, would not allow for a straightfoward interpretation of phrase structure persistence, since word chunking may not be (solely) driven by morpho-syntactic factors (e.g., agreement), but rather by lexical-semantic factors (e.g. semantic coherence, co-occurrence frequency).

In a second experiment, we therefore disentangled these two possibilities, by replacing open class word roots with pseudo-word roots [11,12] in a subset of the stimuli used in the first experiment, thus reducing the lexical-semantic sentence content, while keeping the syntactic constituent structure intact. The use of pseudo-word roots constitutes an optimal control for both semantic coherence and co-occurrence frequency, which in pseudo-word stimuli is close to zero [21]. In Experiment 2, we expected to replicate the results of Experiment 1, as an indication that the regularity patterns unconsciously produced by the subjects were not due to either lexical-semantics biases or the relative frequency of co-occurrence of the words constituting each sentence, but rather to genuine syntactic factors.

The results showed that the subjects could not get rid of the underlying phrase structure, albeit unconsciously. Although prompted to recombine words at random, our subjects consistently produced recombination specific patterns depending on the type of input phrase structure. Moreover, the irrelevance of lexical-semantics biases and of the frequency of word co-occurrence was demonstrated by comparing stimuli formed by actual words with stimuli formed by invented words. We propose that the original methodology presented here highlights the role of the implicit syntactic knowledge that normal human subjects are unconsciously endowed with. Such spontaneous and unbiased constraints confirm the neurobehavioral substance of phrases in a novel manner and may lead to a deeper comprehension of the neural processes underlying phrase structure syntactic processing.

REFERENCES

1. Bloomfield, L. Language. (University of Chicago Press: Chicago, IL, 1933).
2. Moro, A. The boundaries of Babel. (MIT Press: Cambridge, MA, 2008).
3. Fodor, J. A. & Bever, T. G., J. Verb. Learn. Verb. Behav. 4, 414–420 (1965).
4. Johnson, N. F., J. Verb. Learn. Verb. Behav. 4, 469–475 (1965).
5. Abutalebi, J. et al., J. Neurosci. 27, 13762–13769 (2007).
6. Pallier, C. et al., Proc. Natl. Acad. Sci. U.S.A. 108, 2522 –2527 (2011).
7. Dapretto, M. & Bookheimer, S. Y., Neuron 24, 427–432 (1999).
8. Caplan, D. & Gow, D., Brain Lang. 120, 174–186 (2012).
9. Embick, D. et al., Proc. Natl. Acad. Sci. U.S.A. 97, 6150 (2000).
10. Ni, W. et al., J. Cogn. Neurosci. 12, 120–133 (2000).
11. Moro, A. et al., Neuroimage 13, 110–118 (2001).
12. Tettamanti, M. et al., Neuroimage 17, 700–709 (2002).
13. Tettamanti, M. et al., Cortex 45, 825–838 (2009).
14. Musso, M. et al., Nat. Neurosci. 6, 774–781 (2003).
15. Friederici, A. D. et al., Proc. Natl. Acad. Sci. U.S.A. 103, 2458–2463 (2006).
16. Bahlmann, J. et al., Neuroimage 42, 525–534 (2008).

17. Friederici, A. D., Trends Cogn. Sci. 6, 78–84 (2002).
18. Gobet, F. et al., Trends Cogn. Sci. 5, 236–2 (2001).
19. Baddeley, A., Trends Cogn. Sci. 4, 417–423 (2000).
20. Perham N., Marsh, J. E., & Jones, D. M, Q. J. Exp. Psychol–A 62, 1285–91 (2009).
21. Humphries, C., et al., J. Cogn. Neurosci. 18, 665–79 (2006).