Argument Structure Representation: Evidence from fMRI

Einat Shetreet
Tel Aviv University
einat.shetreet@childrens.harvard.edu

Dafna Palti
Tel Aviv University
paltida@post.tau.ac.il

Naama Friedmann
Tel Aviv University
naamafr@post.tau.ac.il

Uri Hadar
Tel Aviv University
Urih1@post.tau.ac.il

Abstract

This paper reports on a series of fMRI experiments testing the processing and representation of various aspects of argument structure of verbs, including the number of complements, the syntactic type of complements, the number of complementation frames, and the optionality of complements. We found that different brain areas are involved in the processing of these different properties.

1 Introduction

Linguistic theory regarding the representation of verbs holds that the lexical entry of verbs includes information about their argument structure (AS). AS specifies the syntactic and semantic environments in which the verb can occur (e.g., Chomsky 1965; Grimshaw, 1979; van Valin, 2001). Several psycholinguistic and neurolinguistic studies have demonstrated that such lexical information affects on-line processing of sentences across different tasks and methods (e.g., Shapiro et al., 1987, 1993; Tanenhaus et al., 1989; Trueswell et al., 1993). The current study used fMRI to examine various lexical-syntactic properties of verbs (number of complements, number of complementation frames, syntactic complexity of complementation frames, and the optionality of complements), to describe the way they influence sentence comprehension and identify their cortical localization, as well as provide evidence appertaining to linguistic controversies regarding verb representation.

2 General Method

The experimental procedure was identical in all the experiments. Hebrew verbs were selected based on the tested property, following judgment procedure by linguists and psycholinguists. In the experiments, each verb was embedded in a few (2-4) sentences. The sentences in each experiment were controlled for the number of phrases, phrase structure, definiteness, duration and frequency. A block design paradigm was used. Each block included 4 sentences and each condition repeated 7 or 8 times. Twelve to nineteen participants were asked, while in the MRI, to listen to the sentences and to decide whether the event described in the sentence is more likely to happen at home or not (for example, for a sentence like "Dan slept in the yellow tent", participants will press a "no" button). This semantic task ensured that participants attended to the sentences and processed them fully. Data was analyzing using SPM2.

3 Experiments

3.1 Experiment 1: Number of complementation frames

It is assumed, based on behavioral studies with reaction times, that all complementation frames of a verb are activated at some stage of processing, regardless of the complement that is used in the sentences. Shapiro et al. (1987, 1989, 1991, 1993) found that this exhaustive access to all complementation frames affects sentence and verb processing such that verbs that have more complementation frames were accessed more slowly than verbs with a single frame. In this experiment (Shetreet et al., 2007), we tested the effect of the processing load of the number of frames on brain activations. This was done by creating a three-point scale, using verbs with one (e.g., *punish*), two (e.g., *discover*) or three complementation frames (e.g., *demand*). The verbs appeared in sentences with either a Noun Phrase (NP) or Prepositional Phrase (PP) complements (e.g., *Dan discovered the mouse in the morning*). Using a parametric design, we looked for brain region in which increasing the number of frames increased the level of activation. We found such graded activation in the left superior temporal gyrus (Wernicke's area), which was assumed to be involved in the processing of the number of complementation options. This assumption was based on the performance of patients with Wernicke's aphasia who did not show sensitivity to the number of complementation options (Shapiro et al., 1993). We also found two clusters of activation in the left inferior frontal gyrus: in BA 47 and in BA 9, which might be involved in selection of competing alternatives (e.g., Thompson-Schill et al., 1997).

In this experiment, we also tried to differentiate between subcategorization frames and thematic frames using verbs that have two subcategorization frames, but one thematic frame (e.g., *nibble* that can appear with either NP or PP complements, both having the thematic role of *theme*). These verbs showed pattern of activation similar to that of verbs with two complementation frames, suggesting that subcategorization cannot be discarded in favor of explanation in purely thematic roles terms, and that it is important for verb processing.

3.2 Experiment 2: Number of complements

Findings from behavioral studies showed that, unlike the number of complementation frames, the number of complements does not affect online processing (Shapiro et al., 1987). Experiment 2 (Shetreet et al., 2007) tested whether the neuronal picture is similar. This was done by comparing verbs that take zero (e.g., *sneeze*), one (e.g., *punish*), or two complements (e.g., *give*), creating a three-point scale of the number of complements. In each sentence, the verb was followed by two constituents, either complements or adjuncts (e.g., two adjuncts: *John sneezed yesterday in bed*; one complement and one adjunct: *Laura broke the glass at midnight*; two complements: *Helen gave the present to Billy*). Here too we used a parametric design to detect graded activations. The pattern of activation in this study crucially differed from that of Experiment 1. The two clusters that showed graded activation according to this gradient have not been traditionally considered to be involved in language processing: one activation cluster was found in the anterior cingulate and one in the medial-precuneus. The activation in the cingulate may stem from its involvement in working memory. Working memory load was expected due to the need to retain a greater amount of information as the number of complements increased. The precuneus has recently been found active in several language studies, including our own (Bachrach, 2008; den Ouden et al., 2009; Shetreet et al., 2009). Bachrach suggested that the precuneus plays a central role in the representation of linguistic syntactic structure. Thus, it seems that the number of complements affected sentence processing, however not in the expected areas (i.e., classic language areas). This may explain the inconsistency with the behavioral results that used interference method. It could be that the resolving the secondary task in the behavioral experiment loaded on linguistic areas, but the processing of the number of complements was done in a different area, using different resources.

3.3 Syntactic complexity of complementation frames

We thus found in Experiment 2 that the number of complements did not load on classic language areas. In this experiment (Shetreet et al., 2009), we tested whether the syntactic complexity of the complement, rather than the number of complements, does show an effect in language regions. For that aim, we used verbs that select sentential complements (CP) or prepositional phrases (PP, e.g., *complain*) and compared them with verbs that select noun phrases (NP) or PPs (e.g., *nibble*). That is, we compared verbs that can take sentential complement and those that cannot. CP complements are syntactically more complex than NP complements, because they include more syntactic layers (lexical Verb Phrase layer, inflectional (IP) layer, and complementizer (CP) layer; Rizzi, 1986). To examine whether the mere inclusion of a CP complement in the lexical entry of the verb, even when the CP was not realized in the sentence, affected the access to the verb, we compared the two verb types when they appeared in the sentence with a PP complement (e.g., *John complained about the cold ice-cream* and *John nibbled at the tasty cake*), thus comparing sentences with identical syntactic structure, but verbs that differ in their lexical information with respect to the syntactic types of their complements. The comparison between verbs that can take a sentential complement and those that cannot yielded activations in bilateral anterior middle temporal gyrus and the precuneus. This indicated that syntactic information regarding the syntactic types of complements in the lexical entry of the verb is reflected in brain activity even when not realized in the sentence.

3.4 Experiment 4: The representation of optional-complement verbs

Finally, we examined the cortical representation of verbs with optional complements, which can appear with and without their complements (e.g., *eat*) in an attempt to provide neurally-based constrains for the linguistic theory (Shetreet et al., 2010). We examined three linguistic approaches for the representation of optional verbs- one that argues that these verbs have two subcategorization frames (one with the complement and one without it; e.g., Engelberg, 2002; van Valin & LaPolla, 1997); an approach that argues that there is one subcategorization frame, with the complement, and its omission is made possible through a syntactic operation (null element; e.g., Cummins & Roberge, 2004); and an approach that argues that there is one frame and that the omission of the complement is made possible through a lexical saturation of the complement (e.g., Bresnan, 1982; Dowty, 1978, 1989). Each of these theories bears different hypotheses with regard to the number of frames and number of complements that sentences with optional complements have. We relied on these distinctions between the theories in our attempt to discriminate between them. First, we assessed the number of frames of verbs with optional complements- to distinguish between the two frames theory and the other two theories, which assume that these verbs have a single complementation frame. To do so, we contrasted verbs with a known number of frames (1 or 2) and compared the identified regions to regions identified in the comparison of verbs with optional complements to verbs with one frame and to verbs with two frames. We found that the comparison between verbs with optional complements and two-frame verbs revealed activations similar to the activation found in the comparison between one- and two-frame verbs. Among the identified regions was the left STG, also identified in Experiment 1 that tested the number of frames. These results suggest that verbs with optional complements have only one frame. In the next stage, we assessed the number of complements in sentences that include verbs with omitted complements. According to the syntactic operation theory, a null element is placed in the position of the omitted complement. Thus, this theory predicts that sentences with omitted complement will be syntactically similar to sentences with a complement. By contrast, according to the lexical saturation account, sentences with omitted complements are similar to sentences containing verbs with no complements, because both are inserted from the lexicon into the sentence without any complement. It is important to note that phonetically null elements like the one assumed by the syntactic theory can be detected by neuroimaging techniques, such as ERP (Featherson et al., 2000; Fiebach et al., 2001; Kluender and Kutas, 1993) or fMRI (Shetreet et al., 2009a). The baseline for this assessment was the comparison between verbs with one complement and verbs with no complements. We contrasted sentences with omitted complements to both no- and one-complement verbs and compared the results of each comparison to the baseline comparison. We found that the sentences with omitted complements were more similar to sentences containing verbs with no complements. One of the areas identified in both of these comparisons was the precuneus that was identified in Experiment 2 in the assessment of activations related to the number of complements. This supports the lexical saturation account for omission of complements. Thus, we concluded that verbs with optional complements have only one subcategorization frame, with the complement, and that a lexical operation enables the complement omission. In addition, by comparing sentences containing verbs with omitted complement to the other conditions, we identified the fusiform gyrus and possibly the temporal-parietal-occipital junction as having a role in lexical saturation and the execution of the omission of optional complements.

4 Conclusion

These experiments revealed on-line effects of some of the critical aspects of verb processing during sentence comprehension, including the number of subcategorization frames and the syntactic properties of the complements. Furthermore, we showed that the processing of lexical-syntactic information regarding the verb's arguments is distributed in a network of regions, which extends the classic language sites. Additionally, the results of this study clearly indicate that the linguistic ideas are reflected in brain activations and provide arguments to decide between linguistics theories.

To conclude, one of the most important and unique aspects of this study is in the interface it suggests between linguistics and neuroscience. The theoretical linguistic framework played a critical role in the interpretation of the brain activations and the brain activations provided neurally-based arguments to linguistic debates. Thus, linguistics and neuroscience can inform and enrich each other, as well as constrain one another and, on the whole, derive scientific gains from the two-way consideration of possible mechanisms.

References

Bachrach, A. (2008). *Imaging neural correlates of syntactic complexity in a naturalistic context*. Doctoral dissertation, MIT.

Bresnan, J. (1982). Polyadicity. In J. Bresnan (Ed.), *The mental representation of grammatical relations* (pp. 149-172). Cambridge, MA: MIT Press.

Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.

Cummins, S., & Roberge, Y. (2004). Null objects in French and English. In J. Auger, C. Clements, & B. Vance (Eds.), *Contemporary approaches to Romance linguistics* (pp. 121-138). Amsterdam: John Benjamins.

Den Ouden, D. B., Fix, S. C., Parrish, T., & Thompson, C. K. (2009). Argument structure effects in action verb naming in static and dynamic conditions. *Journal of Neurolinguistics*, *22*, 196-215.

Dowty, D. (1978). Governed transformations as lexical rules in a montague grammar. *Linguistic Inquiry*, *9*, 393-426.

Dowty, D. (1989). On the semantic content of the notion of ‘‘thematic role’’. In G. Chierchia, B. Partee, & R. Turner (Eds.), *Properties, types, and meanings*, vol. 2 (pp. 69-129). Dordrecht: Kluwer.

Engelberg, S. (2002). Intransitive accomplishments and the lexicon: The role of implicit arguments, definiteness, and reflexivity in aspectual composition. J*ournal of Semantics*, *19*, 369-416.

Featherston, S., Gross, M., Münte, T. F., & Clahsen, H. (2000). Brain potentials in the processing of complex sentences: An ERP study of control and raising constructions. *Journal of Psycholinguistic Research*, *29*, 141-154.

Fiebach, C. J., Schlesewsky, M., & Friederici, A. D. (2001). Syntactic working memory and the establishment of filler-gap dependencies: Insights from ERPs and fMRI. *Journal of Psycholinguistic Research*, *30*, 321-338.

Grimshaw, J. (1979). Complement selection and the lexicon. *Linguistic Inquiry*, *10*, 279-326.

Kluender, R., & Kutas, M. (1993). Bridging the gap: Evidence from ERPs on the processing of unbounded dependencies. *Journal of Cognitive Neuroscience*, *5*, 196-214.

Rizzi, L. (1997). The fine structure of the left periphery. In L. Haegeman (Ed.), (pp. 281-337) *Elements of grammar: A Handbook of generative syntax*. Dordrecht: Kluwer.

Shapiro, L. P., Brookins, B., Gordon, B., & Nagel, N. (1991). Verb effects during sentence processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 983-996.

Shapiro, L. P., Gordon, B., Hack, N., & Killackey, J. (1993). Verb argument processing in complex sentences in Broca and Wernicke’s aphasia. *Brain and Language*, *45*, 423-447.

Shapiro, L. P., Zurif, E. B., & Grimshaw, J. (1987). Sentence processing and the mental representation of verbs. *Cognition*, *27*, 219-246.

Shapiro, L. P., Zurif, E., & Grimshaw, J. (1989). Verb processing during sentence comprehension: Contextual impenetrability. *Journal of Psycholinguistic Research*, *18*, 223-243.

Shetreet, E., Friedmann N., & Hadar U. (2009). An fMRI study of syntactic layers: Sentential and lexical aspects of embedding. *NeuroImage*, *48*, 707-716.

Shetreet, E., Friedmann, N., & Hadar, U. (2009a). The cortical representation of unaccusative verbs. *Language and Brain*, *8*, 21-29. (in Hebrew)

Shetreet, E., Friedmann N., & Hadar U. (2010). The cortical representation of verbs with optional complements: The theoretical contribution of fMRI. *Human Brain Mapping*, *31*, 770-785.

Shetreet, E., Palti, D., Friedmann, N., & Hadar, U. (2007). Cortical representation of verb processing in sentence comprehension: Number of complements, subcategorization and thematic frames. *Cerebral Cortex*, *17*, 1958-1969.

Tanenhaus, M. K., Boland, J., Garnsey, S. M., & Carlson, G. N. (1989). Lexical structure in parsing long-distance dependencies. *Journal of Psycholinguistic Research*, *18*, 37-50.

Thompson-Schill, S. L., D’Esposito, M., Aguirre, J. K., & Farah, M. J. (1997). Role of the left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceedings of the National Academy of Sciences of the USA*, 14792-14797.

Trueswell, J. C., Tanenhaus, M. K., & Kello, C. (1993). Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden-paths. Journal of Experimental Psychology: *Learning, Memory and Cognition*, *19*, 528-553.

van Valin, R. D. (2001). *An introduction to syntax*. Cambridge, UK: Cambridge University Press.

Van Valin, R. D., & LaPolla, R. J. (1997). *Syntax: Structure, meaning and function*. Cambridge, UK: Cambridge University Press.