The Neural Basis of Argument Structure Composition through Eye-Tracking, Focal Brain-Lesion and fMRI

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Abstract

We investigate the processing and neurological basis of Light Verb Constructions (LVCs) such as *The girl gives a kiss (to the boy)* where the thrust of the event argument structure is provided not by the verb *give* but by the NP *a kiss*. LVCs contrasts with "heavy" counterparts (HVC) as in *photograph* in *The girl photographs a kiss (between her friends)*. We examine two questions: 1) whether the heavy reading ($[CAUSE < thing, [event < GO, thing, PATH]]$) is derived from the *light* reading ($[CAUSE < thing, event >]$), or instead the *heavy* reading is lexically stored alongside the light counterpart, and 2) whether LVCs are lexically stored as idioms or instead, they are built compositionally during real-time comprehension. **Study 1** addresses the first question by showing via eye-tracking an increased reading time for the heavy (over the light) condition at the point of the verb, thus supporting the view that LVs are not stored with both readings, but are stored instead with an underspecified/empty semantics. **Studies 2 and 3** address the second question. **Study 2** does so via aphasic comprehension (Broca's vs. Wernicke's vs. intact-brain matching controls) using a sentence-to-picture matching task and **study 3** via event-related fMRI. Results from **Study 2** show a contrast in comprehension whereby, unlike Wernicke's or matching controls, Broca's patients reveal chance-level comprehension for LVCs over HVCs, thus indicating a preferential recruitment of left inferior frontal cortex (LIF cortex) in the comprehension of LVCs. Results from **Study 3** further support the validity of these findings by showing preferential activation for LVCs over HVCs in the LIF cortex and crucially not in the left posterior superior temporal cortex (LPST cortex) associated with Wernicke's area. Altogether, these results support a view of LVCs that is compositional (in real-time terms), semantic in nature, and supported by the workings of the LIF cortex, an area previously robustly associated with argument structure composition.

Keywords: Language comprehension; inferior frontal gyrus; Broca; light verbs; argument structure composition

Background

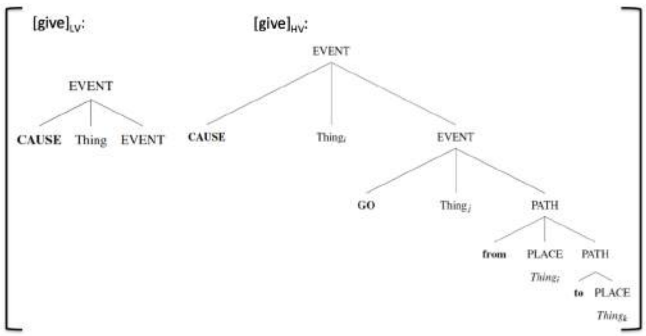
LVCs (light verb constructions) such as *The girl* ***gives*** *a kiss (to the boy)*[1], contrast with semantically heavier counterparts like *The girl* ***photographs*** *a kiss (between her friends)*. Both sentences exhibit the same surface syntax: [NP [V NP]], but only in the LVC the argument structure (AS) of the sentence emerges from the object's meaning *kiss*. Whereas all analyses agree that LVCs result from the integration of the AS of the object into the event argument structure of the sentence $[\text{kiss}_{<} kisser, kissee >]$, they differ in the extent to which they allow the argument structure of the verb $[\text{give}_x, y, z]$ to participate in that event representation (and if so, how). Such differences carry in turn distinct processing and cortical implications. We consider three possible analyses: 1) Ambiguous-Semantics, 2) Empty-Semantics, and 3) Underspecified-Semantics. We discuss each in turn alongside its respective processing implication.

The ***Ambiguous-Semantics analysis*** represents the default analysis according to which LVs[2] are stored with both their light and heavy readings. Accordingly, verbs are retrieved with both meanings and the object plays a crucial role disambiguating between the two senses. The processing implication of this analysis is that retrieval of an ambiguous LV

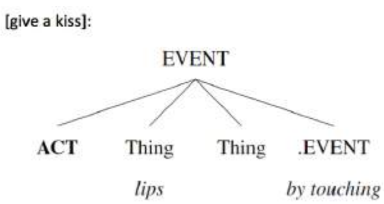
[1]Sometimes, other LVCs such as "the woman gives an order to the man" are in fact ambiguous between a *light* (i.e., the woman orders the man to do something) and *heavy* (i.e., the woman hands the man a piece of paper containing instructions) reading. Here, the label LVC refers to the *light* reading of those sentences.

[2]LV refers to a *light* use of a verb inside a LVC.

will engender a higher cost than retrieval of a non-ambiguous HV because such a process demands 1) retrieval of a verb with two readings and 2) pruning, as it were, the unnecessary meaning from the sentence representation. The Lexico-Conceptual Structure (LCS) of the two readings for *give* is illustrated as follows:

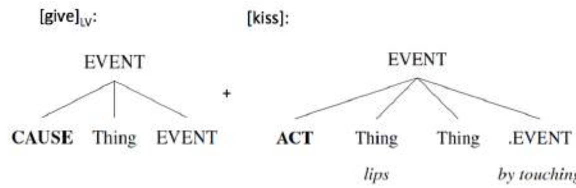


Under the ***Empty-Semantics analysis***, LVs are placeholders with no semantic content (Goldberg,2003, Hale and Keyser, 1993). Their lack of semantic content allows their object to supply the necessary argument structure to the constructions event representation. Accordingly, LVs are lexically stored with their objects in the lexicon as constructions, similar to idiomatic expressions. Since they are stored as individual constructions, they are highly sensitive to frequency factors. Consequently, the main processing implication of this analysis is that LVCs should be retrieved faster than their heavy verb (HV) counterparts because they are more frequent (Piñango et al., 2006). An example of a lexico-conceptual representation of the LVC give a kiss under this analysis is given below:



Finally, the ***Underspecified-Semantics analysis***, proposes that LVCs are formed in real-time by composition of the semantically underspecified verb and the object's AS (Butt,2003, Culicover and Jackendoff,2005). When frequency differences are minimized (although they are never eliminated since LVs are by and large high in frequency) LVC composition may be observed as higher cost during online comprehension in comparison to heavy verb-construction (HVC) counterparts. An example of the two lexico-conceptual representations involved in the LVC give a kiss under this analysis is given below:

Here, we present three studies that evaluate the behavioral and neural correlates of real-time processing of LVCs, and shed light on their compositionality. To forecast, the results support the empty/underspecified semantics of LVs and



the crucial role of left inferior frontal areas during argument structure composition.

Study 1: Empty/Underspecifed Semantics Analyses vs Ambiguous Analysis

Study 1 addresses the question of whether the heavy reading is derived from the light reading, or instead the light reading is lexically stored alongside its heavy counterpart. Previous research on meaning composition has already shown that at least certain kinds of meaning composition translate into more computational work reflected in turn in higher reading times (e.g., Frazier and Rayner (1990), Piñango et al., 1999; Katsika et al., 2012). More to the point, Briem et al, 2009 have already shown results for German consistent with the underspecified-semantics view. That study was done via MEG, with short sentences (with context), and the measure of underspecification was level of brain activation. In the present study we address this question using eye-tracking in English. We measure the unfolding of comprehension in longer multi-phrasal sentences. If it is indeed the case that potential light verbs are stored with underspecified semantics, the underspecified-semantics analysis predicts that, in an LVC, the LV meaning will be activated first, and consequently that the comparatively more costly processing of HVs will lead to longer reading times before the object is fully processed.

Participants

Thirty-six native speakers of English, students at Yale University and all between 18-27 years of age participated in the study.

Materials

The study was embedded in a larger study of multiple conditions that served as fillers to the LVC and HVC conditions. The LVC study consisted of two conditions (LVC and HVC) and 20 sentences per condition. Each sentence was preceded by a context (*On the main deck of the boat,*) and followed by either a LVC (*David* ***gave*** *a shout to Captain McDonald*) or a HVC (*David* ***heard*** *a shout from Captain McDonald*). Verbs and objects were selected based on a corpus analysis of light senses using the Brown Corpus of Written American English (Francis and Kucera, 1964; Hofland et al., 1999) (see Piñango et al., 2006, for details). Thus, for each pair of sentences, verbs and objects were matched in raw frequency and length and sense co-occurrence.

Procedure

The eye-tracker was calibrated using a series of nine fixed targets across the display. Trials consisted of several events. First, a fixation target appeared at the screen position to be occupied by the sentence-initial letter. The context sentence disappeared and the sentence initial fixation target re-appeared. Participants re-fixed their gaze and pressed a button to bring up the critical sentence. They read this sentence and clicked a button when finished.

Results

We observed greater times for *first-pass regression* (i.e., a final first-pass fixation that ends in a backward glance to an earlier part of the sentence) and *regression-path fixation* (i.e., all fixations from the first fixation in a region until the reader fixates to the right of the region) for HVCs at the object (1). This leftward regression back to the verb resulted in greater second-pass fixation times (i.e., sum of all fixation durations in a region that are not first-pass fixations) at the verb. The percentage of correct responses for the comprehension questions was 94%.

Table 1: *Results of Study 1*

Variable	Verb *heard/read*	Object *shout*
First-pass regression (ms)		
Heavy	278.6 (155.5)	**356.1 (196.0)**
Light	273.2 (138.6)	**340.7 (204.6)**
Regression-path fixation (ms)		
Heavy	**358.2 (279.8)**	432.5 (302.3)
Light	**304.1 (182.9)**	429.9 (333.6)
Second-pass fixation (ms)		
Heavy	**120.9 (201.2)**	164.6 (260.6)
Light	**85.9 (171.7)**	140.7 (301.2)

Discussion

As verb-frequency was controlled, the lower reading times for LVs over HVs support both the Empty/Underspecified characterization of LVCs. These results thus replicate those of Briem et al, 2009. Having addressed this preliminary question we proceed to the question of compositionality of LVCs, the central point of the paper.

Study 2: Compositional vs Non-compositional. Focal Lesion Study

Study 2 addresses the second question: whether LVCs are lexically stored as idioms or instead they are built compositionally during real-time comprehension. This question can be studied from a neurological perspective because, as it turns out, argument structure (AS) composition, the umbrella process that presumably underpins LVC composition, has been claimed to target one key language area: the left inferior frontal cortex (LIF cortex) associated with Brocas aphasia and not the left posterior temporal cortex associated with Wernickes aphasia. (Piñago et al.,1999, Burkhardt et al. 2003, Bornkessel et al.,2005, Grewe et al.,2005, Grewe et al.,2006, Raettig et al.,2010).

Accordingly, the underspecified semantics analysis, but not the empty semantics analysis, predicts that only patients with Broca's aphasia (in contrast to patients with Wernickes aphasia and matching controls) will show impaired performance for LVCs (and not for HVCs).

Participants

Twelve participants diagnosed with chronic aphasia (8 females and 4 males, mean age: 55 years old) participated in the study. Seven patients were diagnosed with Broca's aphasia and four with Wernicke's aphasia. A control group of eight education and age-matched controls (six females and two males, mean age: 51 years old) was included for comparison.

Materials

Seventy experimental sentences were constructed. They were distributed along the following conditions: 1) 20 **LVCs**, a combination of a light verb and a noun phrase (e.g., *La mujer* ***hace*** *una llamada* "The woman makes a call"), 2) 10 **HVCs** with a heavy verb and a noun phrase (e.g., *La mujer* ***responde*** *una llamada* "The woman answers a call"), 3) 10 **DVCs** with a dark verb[3] and a noun phrase (e.g., *La mujer* ***hace*** *un dibujo* "The woman makes a drawing"), 4) 20 **fillers Type 1**,which consisted of a non-light verb and a noun phrase (e.g., *La mujer* ***lee*** *un libro* "The woman reads a book", and 5) 10 **fillers Type 2**, which were identical in structure to fillers of Type 1, with the exception that they included a relative clause (e.g., *La mujer que lee un libro esta sentada* "The woman that reads a book is seating") in order to ensure that participants did not suffer from an auditory memory deficit.

Procedure

The experimental sentences were randomized and recorded by two native speakers of Spanish. Simultaneously with the presentation of each sentence, a set of two pictures was presented (Figs.: 1, 2, 3) Each set consisted of a correct and a foil picture. Patients were instructed to choose the picture that represented the best match for the sentence that they had just heard.

Results

In the LV condition, controls and Wernicke's performed significantly better than patients with Broca's aphasia. In contrast, performance between the control group and Wernicke's was not significantly different. The analysis reported an accuracy score of 89% for controls, 92% for Wernicke's patients, and 68% for Broca's. No differences in the number of correct responses were found across groups in the HV condition.

[3] A dark verb (DV) is defined as the heavy counterpart of a LV.

Figure 1: *Example of correct and foil pictures for the sentence:* La mujer hace una llamada*, lit. "The woman makes a call". (top: correct picture, bottom: foil picture).*

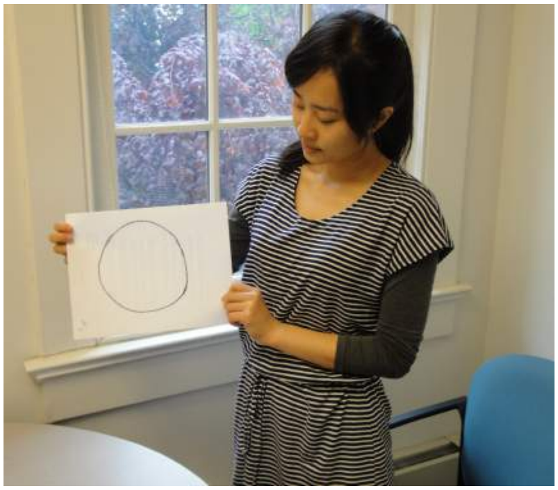
As for the DV condition, control participants achieved significantly higher scores than Wernicke's.

Discussion

The results are consistent with the prediction of compositionality associated with the underspecified semantics analysis, and not with the empty-semantics analysis. According to this prediction, LVCs demand that the underspecified argument structure (AS) associated with the verb and the AS associated with the object be composed into a larger event representation as comprehension unfolds. Argument structure composition is independently associated with the workings of the LIF cortex, Brocas patients exhibit focal lesions in that cortical region exclusively. Consequently Brocas patients should show impaired performance in the interpretation of LVCs. This was indeed the case. Patients with Broca's aphasia performed worse in comprehension of LVCs than Wenickes. Moreover, performance seems to improve as severity of the deficit is reduced (mild Brocas > moderate Brocas). This same cortical

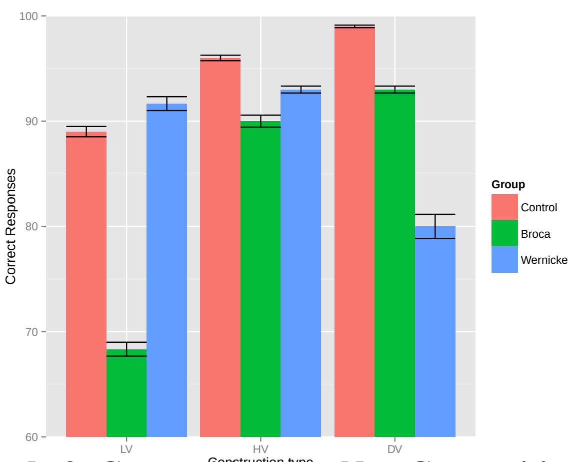
Figure 2: *Example of correct and foil pictures for the sentence:* La mujer responde una llamada*, lit. "The woman answers a call". (top: foil picture, bottom: correct picture).*

Figure 3: *Example of correct and foil pictures for the sentence:* La mujer hace una circulo*, lit. "The woman makes a circle". (top: correct picture, bottom: foil picture).*



region does not seem to play a crucial role in the processing of HVCs/DVCs, as seems clear by the unimpaired performance of Broca's aphasics in these conditions.

Figure 4: *Percentage of correct responses by verb type and experimental group. Error bars indicate the standard error of the mean.*



Study 3: Compositional vs Non-Compositional: fMRI

Study 3 pursues the compositionality question also from a neurological perspective but through the intact brain. Accordingly, it sought to test the prediction that the argument structure composition involved in the creation of LVC's will engender preferential activation in left inferior frontal areas and crucially not the left-posterior temporal cortex (associated with Wernickes area).

Participants

25 participants (11 females and 14 males, mean age: 20; age range: 18-27) entered the final analysis. All were monolingual, native speakers of English and achieved over 85% of correct responses in the behavioral task.

Materials

The four critical sentence conditions for the study are shown in Table 2. Each participant read a total of 100 light verb sentences, 50 heavy verb sentences and 50 dark verb sentences, randomly assigned to 10 fMRI runs. Sentences were presented word-by-word with an ISI of 500 milliseconds.

Table 2: *Experimental Sentences in Study 3.*

Condition	Example
Light Verb (LV1)	Mr. Olson **gave** an **order** to the produce guy at the market.
Heavy Verb (HV)	Mr. Olson **typed** an **order** to the produce guy at the market.
Light Verb (LV2)	The **order** that the English department chair **gave** to the postdoc was completely ignored.
Dark Verb (DV)	The **letter** that the English department chair **gave** to the postdoc was completely ignored.

As can be seen in Table 2, the contrast LV1 and HV presented the verb before the object, whereas the contrast LV2 and DV presented the object first, then the verb. This was done in order to study whether the order of processing influences compositionality. Wittenberg and Piãngo (2012) had already shown that in German, a language with SOV order (e.g. *eine Referat hielt*, lit.:"a speech gave"), it is the choice of the verb that determines whether the argument structures associated with the NP complement and the verb respectively need to be integrated. This experimental design examines whether in English the verbs AS may play a similar crucial role.

Procedure

fMRI study in which participants viewed sentences in a segmented manner, word by word, at the center of the screen. During comprehension task trials, participants had to answer a question by making a button press (right index finger for yes, right thumb finger for no).

Results

Results show that LVC composition preferentially recruits the left inferior frontal gyrus (LIFG). Figure 5 illustrates the results for the contrast LV1-HV and Table 3 below shows the corresponding Talairach coordinates. Major activations in response to this interaction were observed in the LIFG, which includes Broadmann areas BA47, BA45, BA44 and BA46, extending up into area BA10; and in the anterior cingulate cortex (ACC) extending up into BA8 and BA6. These activations were recorded from the start of the sentence up to the offset of the object. After the object, no differences in activation were observed between the LV1 and HV conditions. As for the LV2-DV contrast, there were no significant differences in activation.

Figure 5: Averaged activation for the interaction between LV1 and HV.

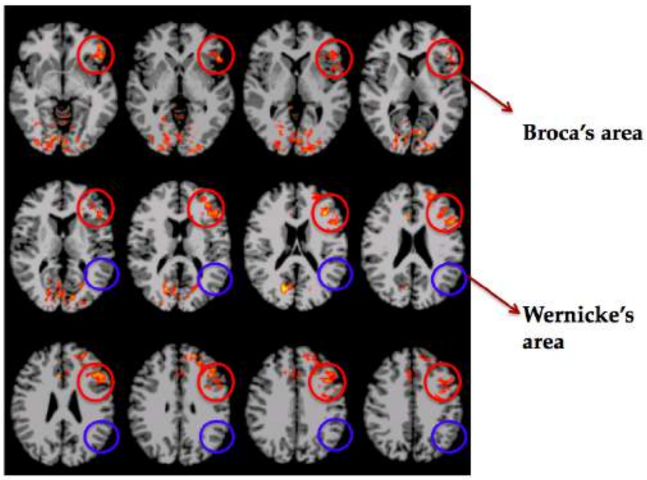


Table 3: *Talairach coordinates, maximal values and volumes of the activated regions for the local maxima in the interaction contrast LV x HV.*

Region	Talairach coordinates	Max.value	Volume (mm^3)
Cerebellum	16, -80, -29	7854	29873
Visual cortex	-8, -72, 9	7358	10726
LIFG: BA47, BA45, BA44, BA6, BA8-10	5, 20, 23	14405	21190

Discussion

The results provide further evidence for the compositionality of LVCs because LIF cortex have been associated with processing of argument structure composition. Interestingly we also observed enhanced activation in the cerebellum. Previous evidence indicates that this region supports language processing indirectly through its connections with frontal areas (Booth et al.,2007; Alexander et al., 1986; Clower et al., 2005; Dum and Strick, 2005; Middletong and Strick, 1994, 1996). Our findings provide evidence for this role of the cerebellum.

We did not find significant activations in the contrast LV2 vs DV. In this condition, the object was presented much earlier than the verb (*The **letter** that the English department chair **gave**...* vs. *The **order** that the English department chair **gave**...).* We argue that the lack of differences in activation is due to the fact that, when the verb is encountered, the event representation is already partially constructed as most of the event's arguments have been provided (i.e., the kisser and the kissee arguments have been processed). This means that when the finally verb is encountered supplying its underspecified argument structure, the compositional process for the event representation of the clause have already been sketched out, thus attenuating the differences between the two sentences and presumably making less visible any differences in hemodynamic response between the two conditions. This contrast aside, the LV-HV results are consistent with those found in Study 2 and with previous studies which find further support in previous evidence associating argument structure composition with left inferior frontal cortex. (?, ?, ?, ?, ?)

Conclusion

The results from Study 1 support the claim that LVs, such as *give, take,get*, are empty/underspecified in meaning in comparison to HVs, such as *type, shred, write, send*. Studies 2 and 3 provide evidence in favor of the compositional analysis of LVCs. A focal-lesion study showed that a damage to Broca's area, which has been associated with argument structure composition, causes difficulties in comprehension of LVCs. By contrast, comprehension of non-light counterparts is unimpaired in these patients. In addition, an fMRI study provided finer-grained details of the areas involved in real-time comprehension of LVCs. We found that comprehension of LVCs relies mainly on left BA 44, 45 and 47. These findings support the compositional process of LVCs because these areas have been traditionally associated with composition of argument structure. The processing and neurological behavior of LVCs speak to an architecture of language whereby semantic composition is taking place partially independently and parallel to syntactic composition.

Acknowledgments

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