# Complement Coercion as the Processing of Aspectual Verbs: Evidence from Self-Paced Reading and fMRI

**Yao-Ying Lai (yao-ying.lai@yale.edu)**
Department of Linguistics, Yale University,
370 Temple Street, New Haven, CT 06520 USA

**Cheryl Lacadie (cheryl.lacadie@yale.edu)**
Yale Magnetic Resonance Research Center
300 Cedar Street, New Haven, CT 06520 USA

**Todd Constable (todd.constable@yale.edu)**
Yale Magnetic Resonance Research Center
300 Cedar Street, New Haven, CT 06520 USA

**Ashwini Deo (ashwini.deo@yale.edu)**
Department of Linguistics, Yale University,
370 Temple Street, New Haven, CT 06520 USA

**Maria Mercedes Piñango (maria.pinango@yale.edu)**
Department of Linguistics, Yale University,
370 Temple Street, New Haven, CT 06520 USA

**Abstract**

Verbs like *begin* and *enjoy* have been assumed to select for events and would coerce an entity-denoting complement to an event in semantic representation; such type-shifting operation engenders additional processing cost. However, recent studies show that this effect is observable only for aspectual verbs (e.g. *begin*), but not psychological verbs (e.g. *enjoy*), suggesting the set of "coercion verbs" is heterogeneous. We hypothesize that aspectual verbs select for structured individuals instead of events. They lexically encode a set of functions, each applying on a dimension (e.g. *eventive, informational, spatial*) denoted by the complement. The parser must determine the verb's specific function and the dimension from the complement. The processing cost results from (1) exhaustive activation of the verb's lexical functions and (2) resolution of ambiguity created by dimension extraction from the complement. We show that processing aspectual verbs was more costly than psychological verbs and that it recruited Wernicke's area for cost 1 and LIFG for cost 2.

**Keywords:** complement coercion; aspectual verbs; semantic composition; semantic-syntax mismatch; type-shifting; ambiguity resolution.

## Introduction

### The Complement Coercion Phenomenon

It has been proposed that verbs like *begin* and *enjoy* carry a selectional restriction and must combine with an event-denoting complement (Pustejovsky 1995, Jackendoff 1997). Supporting evidence comes from the observation that even in sentences where the complement denotes an individual of the ordinary sort, only an eventive interpretation is obtained. That is, a sentence like (1) can only be interpreted as making reference to some event involving a book with John as its agent.

(1) *John began enjoyed the book.*
(2) *John began/enjoyed reading/writing the book.*

The contrast in (1) and (2) has been interpreted as an instance of the broader phenomenon of **type coercion**. The hypothesis is that complements denoting ordinary individuals cannot directly compose with a class of verbs (including aspectual, psychological, and some others), leading to a mismatch in the semantic representation. This mismatch is resolved by a semantic operation, *type-shifting* (Partee, 1983; Partee & Rooth, 1983), that coerces the semantic type of the entity-denoting complement into the appropriate event-denoting type.

Experimental investigation of this phenomenon has revealed behavioral and neurological patterns that are taken to support this linguistic analysis. Psycholinguistic studies, using a variety of experimental paradigms, report that combining an entity-denoting complement with a coercion verb (*John began the book*) engenders more processing cost than combining it with a non-coercion verb (*John read the book*) during real-time comprehension (Frisson & McElree, 2008; Katsika et al., 2012; McElree et al., 2001; McElree et al., 2006; Pickering, McElree, & Traxler, 2005; Pickering et al., 2006; Traxler, Pickering, McElree, 2002; Traxler et al., 2005). On the neurolinguistic side, it has been found that

the complement coercion effect recruits three distinct cortical regions: Wernicke's area (Piñango & Zurif, 2001), ventro-medial prefrontal cortex (vmPFC) (Pylkkanen & McElree, 2007), and BA45 (Husband, Kelly, & Zhu, 2011). The additional cost has been interpreted as manifesting type-shifting operation or the mechanism of building an eventive representation from an entity-denoting expression, and the observed patterns in particular brain areas have been interpreted as evidence that these areas implement type-shifting and coercion.

## Challenges to the Type-shifting Hypothesis

The type-shifting hypothesis faces challenges in two respects. The first challenge comes from the distribution of the linguistic data. At least a subset of coercion verbs does not necessarily require an event-denoting complement, as in (3 & 4), casting doubt on the empirical generalization underlying the type-shifting analysis.

(3) *The editor's comments finish the magazine.*
(4) *This famous perch begins the Appalachian Trail.*

The second challenge comes from real-time implementation. It turns out that only a subset of coercion verbs engender additional processing cost. Katsika et al. (2012) and Utt et al. (2013) show that the coercion effect is observable only with the aspectual verbs (e.g. *begin, finish, start*), which modify temporal reference, but not with psychological verbs (e.g. *enjoy, prefer, endure*), which denote mental states. Studies on complement coercion have conflated the two classes and included additional unclassified verbs such as *try* and *master*. The set of "coercion verbs" investigated in the prior literature is thus semantically heterogeneous, and subclasses within this set do not in fact show an identical processing profile.

These observations suggest that the type-shifting hypothesis is problematic both in terms of its empirical coverage and experimental implementation. In what follows, we present an alternative hypothesis focusing on aspectual verbs, which do clearly exhibit processing cost.

## The Dimension Ambiguity (DA) Hypothesis

Piñango & Deo (2012) propose that aspectual verbs lexically select for structured entities, which can be conceptualized as having a totally ordered structure along some dimension (e.g. temporal, spatial, eventive, etc.). They do not exclusively require an event but specify a relation between a structured individual and a subpart thereof relative to an axis over which the individual extends (Piñango & Deo, 2012). Specifically, the lexical semantics of aspectual verbs involves a function *f* that applies to a subject denotation *x* and a object denotation *y* such that *f*(x) is a minimal subpart of *f*(y).

In (4), the aspectual verb (*begin*) introduces a function that maps individuals to their spatial extent, and the complement (*the Appalachian Trial*) is conceptualized as a spatially structured individual extending upon a spatial axis that consists of ordered subparts. Sentence (4) is true iff the spatial extent of this famous perch is the initial subpart of the spatial extent of the Appalachian Trial.

More generally, sentences containing aspectual verbs are understood to make reference to parthood relations between objects along a range of dimensions, such as the spatial, the temporal, the eventive, and the informational dimension, exemplified by (4), (5), (6), (7) respectively.

(5) *A thunderstorm began the morning.*
(6) *A prayer started the banquet.*
(7) *The next lemma finishes the proof.*

These dimension-specific functions are taken to be lexically associated with the lexical entries of aspectual verbs. Because there are several such functions, the interpretation of aspectual verbs is underdetermined and depends on which dimension is relevant for the interpretation in a given context of utterance.

This indeterminacy also obtains in the case of the so-called "coercion" uses of aspectual verbs. A sentence like *John began the book* is in fact ambiguous between two possible interpretations. The salient one is an interpretation along the eventive dimension (*John began reading/writing/etc. the book*), where the individuals *John, the book* get mapped to the event that they participate in. However, the sentence has another, constitutive interpretation where the individuals *John, the book* get mapped to an informational structure, such that some piece of information corresponding to John is an initial subpart of the information corresponding to the book (e.g. a story about John is the first story of the book). The context determines the intended interpretation, although one interpretation might be more salient than the other.

This analysis, that we label the **Dimension Ambiguity** analysis, makes no assumptions about selectional restrictions and type-shifting operations to resolve mismatches. Aspectual verbs combine with their complements and subjects just like regular verbs but their full interpretation requires the contextual resolution of an ambiguity—the specific dimension along which the complement can be construed as a structured individual. The observed psycho- and neuro-linguistic reflexes of complement coercion are taken to reflect ambiguity resolution and not type-shifting operations. This allows us to not only maintain a uniform semantics for aspectual verbs across its uses, but also captures the observation from Katsika et al. (2012) that aspectual verbs, but not psychological verbs, engender additional cost.

This is how the processing of aspectual verbs is hypothesized to be implemented in real time:

(A) When a reader encounters an aspectual verb, they retrieve the verb together with a number of

dimensional functions that are encoded in the verb's lexical entry. These functions each correspond to a specific dimension (e.g., temporal, spatial, eventive…). We call this process the **exhaustive activation of lexical functions**. For any argument to the verb, it is possible that there is more than one dimension relative to which it can be interpreted as being a structured individual.

(B) To get an interpretation for the composition of the aspectual verb and the complement, readers must determine the dimension along which the complement denotation is construed as a structured individual. That is, they must choose a particular function among those encoded in the verb to determine the interpretation. This is a case of **ambiguity resolution**. Once the function is chosen, the complement can be construed as a structured individual along the dimension given by that function.

Thus, the processing cost associated with aspectual verbs results from (A) exhaustive activation of the verb's lexical functions (Shapiro, Zurif, & Grimshaw, 1989), and (B) resolution of ambiguity created by immediate composition demands (i.e. dimension extraction from the complement) (Frazier & Rayner, 1990). We suggest that the cost observed within aspectual verbs in previous psycholinguistic studies is associated with (B), ambiguity resolution. In addition, the neurological findings are consistent with both step (A) and step (B). That is, activating the lexical functions of aspectual verbs might recruit a localizable brain region without engendering observable cost in psychological measurement. On the other hand, ambiguity resolution may induce observable cost during real-time comprehension while recruiting a specific brain region.

### This Study

Our study aims to examine the psychological viability of the Dimension Ambiguity analysis and to explore its psychological implementation. We attempt to pin down the processing cost associated with aspectual verbs and to investigate its neural correlates. We have dissociated aspectual verbs from psychological verbs, since only the former involves the retrieval of multiple functions and the resolution of dimension ambiguity.

We present a self-paced reading experiment and an fMRI experiment, along with a pretest questionnaire. Three verb types are considered: aspectual verbs (AspectualV), psychological verbs of the *enjoy*-type (EnjoyingV), which are categorized as coercion verbs in the type-shifting account, and psychological verbs of the *love*-type (LovingV), which involve no coercion and thereby serve as controls. All sentences contain an animate subject and an entity-denoting complement.

Based on the DA hypothesis, we predict that aspectual verbs will induce longer reading times than either type of psychological verbs in the self-paced reading because the former involve resolution of an ambiguity. With respect to neural correlates, we expect aspectual verbs to recruit additional cortical areas at two positions corresponding to the two processes mentioned above: (a) when an animate subject combines with an aspectual verb, where the parser exhausts the verb's lexical functions, and (b) when the aspectual verb combines with the complement, where the parser mines the complement denotation to determine a dimension (e.g. spatial, temporal, eventive, informational).

## Pretest: Norming questionnaire

To ensure the equal acceptability of the manipulated conditions, we employed a rating questionnaire.

### Method

Forty native speakers of American English took the questionnaire, all between the ages of 18-30 and without reading disabilities. The data of three participants were discarded because their responses were either undifferentiated or inconsistent. We created 50 triplets; each contained the three conditions as shown in Table 1.

Table 1: Conditions and sample sentences

| Condition | Example sentences |
|---|---|
| | *Lady Gaga* |
| AspectualV | *started* |
| EnjoyingV | *preferred* |
| LovingV | *loved* |
| | *this CD of American pop hits.* |

With 150 filler sentences introduced, the whole set of the stimuli amounted to 300 sentences. These stimuli were divided into two scripts, each randomly assigned to 20 participants. The participants were asked to rate the sensibility of each sentence from a 1-5 scale (1=nonsensical; 5=sensical) and answer a multiple-choice, multiple-answer question probing possible interpretations.

### Results

The repeated measures Analysis of Variance (ANOVA) showed that the three conditions were within the acceptable range, shown in Table 2.

Table 2: Results of the sensicality rating (N=37)

| Condition | Mean | Standard deviation |
|---|---|---|
| AspectualV | 4.13 | 0.75 |
| EnjoyingV | 4.31 | 0.52 |
| LovingV | 4.80 | 0.22 |

Planned pairwise comparisons indicated a significant difference between AspectualV and LovingV ($p < .001$) as

well as between LovingV and EnjoyingV ($p$< .001). Crucially, no difference was found between AspectualV and EnjoingV ($p$< .082). The reliability test showed that the items used in each condition were highly reliable (Cronbach's alpha: AspectualV=0.92; EnjoyingV=0.85; LovingV=0.72).

## Experiment 1: Self-paced Reading

We conducted a self-paced reading experiment with a moving window paradigm to investigate the time-course of the cost underlying the processing of aspectual verbs and the *enjoy*-type of psychological verbs; the two are collapsed as "coercion verbs" under the type-shifting account. The *love*-type of verbs served as the control.

### Method

Twenty-eight native speakers of American English were recruited, all between the ages of 18-30 and without history of reading disabilities.

The materials were adapted from the pretest questionnaire. Each sentence was segmented into several windows as shown below. Our windows of interest were the verb, complement NP, NP+1, and NP+2 regions.

[*Lady Gaga*]$_1$ [***started***$_{(\text{AspectualV})}$ / ***preferred***$_{(\text{EnjoyingV})}$ / ***loved***$_{(\text{LovingV})}$]$_2$ [*this CD*]$_3$ [*of*]$_4$ [*American*]$_5$ [*pop hits.*]$_6$

The participants read the sentences segment by segment at their own pace, which allowed them to fully understand the sentences' meanings. At the end of the sentence, they were asked a question probing either sensicality or the content of the sentence just read to ensure comprehension.

### Results

The accuracy of the comprehension task was 95.03%. Results of the reading task are reported in Table 3 and Figure 1. No significant effect of condition was found at the verb ($F_1$(2,54)=2.45, $p$< .096; $F_1$(2,98)=2.20, $p$< .117) or at the complement NP ($F_1$(2,54)=1.13, $p$< .331; $F_2$(2,98)=0.69, $p$< .502). Significant differences appeared at NP+1 and NP+2.

Table 3: Results of reading times in millisecond (standard errors in parenthesis)

| | Verb | ComplementNP | NP+1 | NP+2 |
|---|---|---|---|---|
| AspectualV | 553.45 (7.30) | 608.01 (8.70) | 502.08 (7.13) | 538.99 (9.07) |
| EnjoyingV | 556.42 (7.26) | 611.64 (9.61) | 483.78 (5.55) | 511.82 (7.38) |
| LovingV | 537.93 (6.58) | 598.98 (9.34) | 474.50 (5.28) | 511.49 (7.59) |

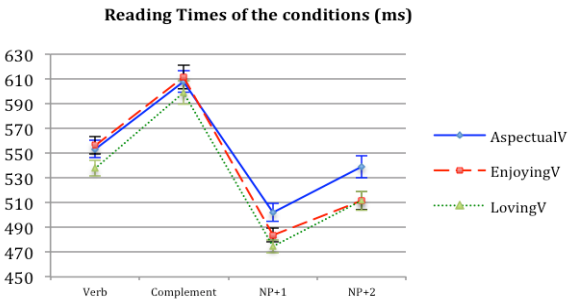


Figure 1: Results of reading times (ms)

At NP+1 position, there was a significant effect of condition ($F_1$(2,54)=3.67, $p$< .032; $F_2$(2,98)=6.84, $p$< .002). The pairwise comparisons indicate that AspectualV engendered significantly longer reading times (RTs) than EnjoyingV ($F_1$(1, 27)=5.45, $p$< .027; $F_2$(1, 49)=6.10, $p$< .017) and LovingV ($F_1$(1, 27)=5.33, $p$< .029; $F_2$(1, 49)=10.13, $p$< .003) respectively. The NP+2 position revealed the same pattern. A significant effect of condition was found ($F_1$(2,54)=4.16, $P$< .021; $F_2$(2,98)=7.03, $p$< .001). The pairwise comparisons suggest that AspectualV engendered longer RTs than both EnjoyingV ($F_1$(1, 27)=7.17, $p$< .012; $F_2$(1, 49)=9.20, $p$< .004) and LovingV ($F_1$(1, 27)=4.64, $p$< .040; $F_2$(1, 49)=9.68, $p$< .003).

Overall, the results indicate that aspectual verbs induced longer RTs than both the *enjoy*-type and the *love*-type of psychological verbs at the two windows following the complement, while the two types of psychological verbs did not differ. We suggest that this is because aspectual verbs, but not psychological verbs, involve ambiguity resolution: readers have to determine one dimension along which the sentence is interpreted among multiple ones (e.g. *eventive* and *informational*).

## Experiment 2: fMRI

Previous neurological studies of the complement coercion effect report activities in three distinct brain regions: Wernicke's area in Piñango & Zurif's (2001) lesion study, ventral medial prefrontal cortex (vmPFC) in Pylkkänen & McElree's (2007) MEG study, and BA45 in Husband, Kelly, & Zhu's (2011) fMRI experiment. Despite the discrepant results, all these studies attribute the effect to type-shifting the complement to obtain an event interpretation. Notice that these experiments are subject to the heterogeneous stimuli problem, mixing aspectual verbs, psychological verbs, and control verbs (e.g. *master, try*). Yet as mentioned, recent studies (Katsika et al., 2012; Utt et al., 2013) indicate that only aspectual verbs engender additional costs. On the other hand, the DA hypothesis accounts for the complement coercion effect as the processing of aspectual verbs. In our fMRI experiment, we aim to investigate its neural

basis, expecting to find brain activities corresponding to the two hypothesized processes associated with it.

## Method

Sixteen native speakers of American English participated this study, all between the ages of 18-30, right-handed, without reading disabilities or history of neurological disorders. The data from one participant was excluded from the analysis due to severe head movement. The stimuli were the same as Exp. 2, with a different set of fillers. We adopted an event-related paradigm. The visual stimuli were presented segment-by-segment as in Exp. 2, each lasting for 500 ms.. For 75% of the sentences, the participants were queried with yes/no comprehension questions, each lasting for 4000 ms.

Each sentence was divided into two events that correspond to the two hypothesized processes induced by aspectual verbs under the DA account, shown in Table 4. Event 1 included the subject and the verb; Event 2 included the complement until the sentence-final word. We hypothesize that the exhaustive activation of an aspectual verb's functions occurs at Event 1 when readers encounter the verb (Shapiro, Zurif, & Grimshaw, 1989), and that readers attempt to determine a dimension denoted by the complement at Event 2 while facing the semantic ambiguity in aspectual verbs (Frazier & Rayner, 1990).

Table 4: Event segmentation in the fMRI experiment

| | Event 1 [Subj+V] | Event2 [Complement ~] |
|---|---|---|
| AspectualV | *Lady Gaga* <u>*started*</u> | *this CD of ……* |
| EnjoyingV | <u>*preferred*</u> | |
| LovingV | <u>*loved*</u> | |

## Results

The overall accuracy of the comprehension task was 88.6%. The response times for the questions are shown in Table 5. Results of repeated measures ANOVA revealed no significant effect of conditions in the response times.

Table 5: Subjects' mean response time by condition

| Condition | Mean | Standard Error (se) |
|---|---|---|
| AspectualV | 1684.18 | 25.06 |
| LovingV | 1651.49 | 24.09 |
| EnjoyingV | 1722.11 | 25.08 |

The imaging results showed that, at Event 1 (Subject + Verb), AspectualV recruited Wernicke's area (BA40) and bilateral BA7, 6, 24 over EnjoyingV (Figure 2). At Event 2 (complement~), AspectualV preferentially recruited the left inferior frontal gyrus (LIFG), including BA44, 44, 47, and left insula over the control LovingV (Figure 3).

The Dimension Ambiguity hypothesis captures these patterns as follows: At Event 1, the BA40 activation (green) reflects the exhaustive activation of the aspectual verb's dimension functions. Importantly, BA7 (pink), which is reported to support spatio-temporal tasks, was preferentially recruited for AspectualV; the activation is likely to reflect the conceptualization of the structured individual. Because the DA hypothesis holds that aspectual verbs select for structured individuals along some dimension axis, we take it as evidence favoring the DA hypothesis over the type-shifting hypothesis. At Event 2, the LIFG and insula activations may reflect the process of determining the dimension along which the complement axis is structured. While our results are connectable with Piñango & Zurif's (2001) and Husband et al.'s (2011) studies, we further clarify the problem of heterogeneous stimuli present in previous works and account for the effect as the processing of aspectual verbs.

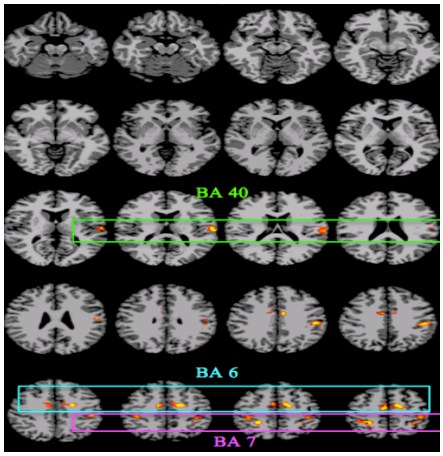

Figure 2: AspectualV – EnjoyingV at Event 1 (Subj+V)

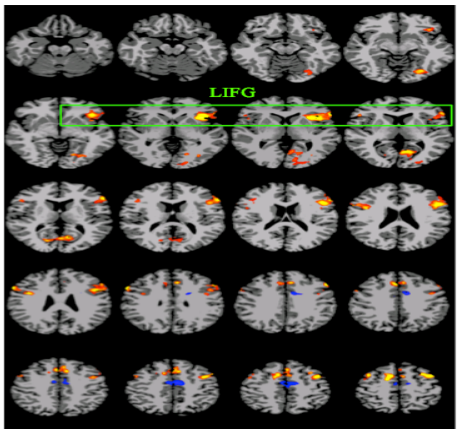

Figure 3: AspectualV–LovingV at Event2 (Complement ~)

## Discussion & Conclusion

Our self-paced reading experiment showed that aspectual verbs engendered longer RTs than psychological verbs during real-time comprehension but only after the complement had been encountered. The

fMRI experiment revealed that aspectual verbs induced preferential recruitment of the left posterior superior temporo-parietal cortex (i.e., Wernicke's area) when readers encountered the verb and the left inferior frontal cortex (i.e., Broca's area) when readers encountered the complement, over each of the psychological conditions (*enjoy*-type and *love*-type respectively).

Our results are therefore consistent with the Dimension Ambiguity analysis, which suggests that aspectual verbs, but not psychological verbs, involve the resolution of dimension ambiguity arising from multiple lexical functions, therefore engendering additional cost. Obtaining the interpretation for a sentence containing an aspectual verb involves (a) exhaustively activating a set of functions encoded by the aspectual verb, and (b) determining the dimension of the complement denotation along which the structure or axis is construed. Our fMRI results suggest that the former process recruits Wernicke's area (BA40), which supports the activation of lexico-semantic representation, and the latter process recruits the LIFG, which supports ambiguity resolution.

Finally, the DA analysis captures a distinction between aspectual and psychological verbs in a linguistically principled manner. It also distinguishes between lexical and compositional semantic processes in brain architectures. Our study represents an implementation of the analysis, working out its psychological viability. We suggest that the complement coercion effect is better understood as involving the composition and processing of aspectual verbs rather than special semantic operations such as type-shifting.

## Acknowledgement

Research was funded by NSF-BCS grant BCS-0643266 to Maria M.Pinango, and NSF-INSPIRE Grant CCF-1248100 to Maria M. Pinango, Ashwini Deo and Todd Constable.

## References

Frazier, L. & Rayner, K. (1990) Taking on semantic commitments: Processing multiple meanings vs. multiple senses. *Journal of Memory and Language 29*,181–200

Frisson, S. & McElree, B. (2008). Complement coercion Is not modulated by competition: Evidence from eye movements. *Journal of Experimental Psychology: Learning, Memory and Cognition, 34(1),* 1-11.

Husband, E.M., Kelly, L,. & Zhu, D. (2011) Using complement coercion to understand the neural basis of semantic composition: Evidence from an fMRI study. *Journal of Cognitive Neuroscience* 23 (11), 3254-3266.

Jackendoff, Ray. (1997). The architecture of the language faculty. The MIT press.

Katsika, A., Braze, D., Deo, A. and Piñango, M.M. (2012). Mechanisms in complement coercion: distinguishing between type-shifting and pragmatic inferencing. *The Mental Lexicon, 7.1,* 58-76.

McElree, B., Pylkkänen, L., Pickering, M.J., & Traxler, M. (2006). The time course of enriched composition. *Psychonomic Bulletin & Review, 13*, 53-59

McElree, B., Traxler, M. J., Pickering, M. J., Seely, R. E., & Jackendoff, R. (2001). Reading time evidence for enriched composition. *Cognition, 78*, B17-B25

Partee, B. (1987). Noun phrase interpretation and type-shifting principles. In J. Groenendijk, D. de Jongh, & M. Stokhof (Eds.), *Studies in discourse representation theory and the theory of generalized quantifiers*. Dordrecht: Foris.

Partee, Barbara, and Mats Rooth, (1983). Generalized conjunction and type ambiguity. In R. Bäuerle, C. Schwarze and A. von Stechow, *Meaning, use and interpretation of language*. Berlin, Germany:De Gruyter.

Pickering, M. J., McElree, B., Frisson, S., Chen, L., & Traxler, M. J. (2006). Aspectual coercion and underspecification. *Discourse Processes, 42*, 131-155.

Pickering, M. J., McElree, B., & Traxler, M. J. (2005). The difficulty of coercion: A response to de Almeida. *Brain & Language, 93*, 1–9.

Piñango, M. M., & Ashwini Deo (2012). Aspectual verbs and the "coercion" effect. Paper presented at SALT 22, May 18–20, Chicago, IL.

Piñango, M. M., & Zurif, E. B. (2001). Semantic operations in aphasic comprehension: Implications for the cortical organization of language. *Brain and Language, 79(2)*, 297–308

Pustejovsky, J. (1991). The generative lexicon. *Computational Linguistics, 17*.

Pustejosvky, J. (1995). *The generative lexicon*. The MIT press.

Pylkkänen, L., Llinas, R., & McElree, B. (2007) An MEG study of silent meaning. *Journal of Cognitive Neuroscience.*

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

Traxler, M., McElree, B.,Williams, R.S. & Pickering, M.J. (2005). Context effects in coercion: Evidence from eye-movements. *Journal of Memory and Language, 53*, 1-25.

Traxler, M. J., Pickering, M. J., & McElree, B. (2002). Coercion in sentence processing: Evidence from eye-movements and self-paced reading. *Journal of Memory and Language, 47*, 530–547.

Utt., J., Lenci, A., Pado, S., & Zarcone, A. (2013) The curious case of metonymic verbs: A distributional characterization. *Towards a Formal Distributional Semantics-IWCS 2013 Workshop.*