Composition of multiple dimension representations in context during real-time comprehension

Yao-Ying Lai[†], David Braze[‡], and Maria Mercedes Piñango[†]

[†]Department of Linguistics, Yale University
370 Temple Street, New Haven, CT 06510, U.S.A.

[‡]Haskins Laboratories
300 George Street#900, New Haven, CT 06511, U.S.A.

E-mail: †yaoyinglai@gmail.com

Abstract

We investigate the role of context in the comprehension of competing semantic representations of sentences with aspectual verbs (AspVs). On the Structured Individual Hypothesis, AspVs select for structured individuals as their complement, construed as a directed axis along various dimensions. During comprehension, the verb's lexical functions are exhaustively retrieved and the AspV+complement composition yields multiple mutually exclusive dimension representations, which are later constrained by context. Results from this eye-movement study show that AspV sentences engender additional processing cost independent of context. That is, while processing multiple dimension representations is costly, the exhaustive lexical retrieval and dimension composition are initially encapsulated from context.

Keywords: Structured individuals; aspectual verbs; semantic composition; context; sentence processing

1. Introduction

We investigate the processing of sentential meaning composition via aspectual verbs (e.g. *begin*, *finish*, *continue*). On the Structured Individual Hypothesis, sentences with aspectual verbs (AspVs) involve morpho-syntactically underspecified composition—having one syntactic structure yet multiple semantic representations.

For instance, sentence (1a) with an AspV gives rise to an agentive reading along the eventive dimension as in (1b), in which the subject denotation is conceived as an agent (actor) performing some event involving the complement denotation. In addition, (1a) can give rise to a constitutive reading as in (1c), in which the subject denotation is conceived as a subpart of the complement denotation. The reading (1c) can be interpreted along the spatial dimension in which the complement refers to a physical entity, or along the informational dimension in which the complement refers to a body of informational content.

(1a) Dave started this CD of classic Jazz hits.

→ (1b) *Dave started recording this CD....*

→ (1c) *Dave's song was the first track on this CD....*

That is, AspV sentences are semantically ambiguous between an agentive reading along the eventive dimension and a constitutive reading along the informational/spatial dimension. The semantic composition involved in AspV sentences yields multiple dimension interpretations—eventive, informational, spatial, etc.

The **question** we ask in this study is: whether the processing of multiple semantic representations could be influenced by context. We answer this question by investigating the role of context in the real-time comprehension of AspV sentences. To this end, we manipulate different context types, biasing vs. neutral, prior to AspV sentences and examine the profiles of these sentences.

Previous studies have shown that sentences with aspectual verbs induced additional processing cost and localizable brain activity (Katsika et al. 2012; Lai et al. 2016, in press; DiNardo et al. 2015). However, those studies examined AspV sentences in isolation without context. It still remains a question whether (and how) context would modulate the processing of AspV sentences that involve multiple semantic representations.

In what follows, we first introduce Piñango & Deo's (2015) formal semantic analysis, which captures the meaning of AspV

sentences (Section 1.1), then present our hypothesis for the influence of context on the real-time comprehension of AspV sentences (Section 1.2). The remainder of the paper reports an eye-movement experiment that tests the hypothesis.

1.1 The Structured Individual Analysis for aspectual verbs

Piñango & Deo (2012, 2015) propose that aspectual verbs require their complement to denote a *structured individual*, defined as an entity that can be conceptualized as a one-dimensional path structure (i.e., axis) along some ontological dimensions (Figure 1).

Figure 1: Structured Individual along a directed path structure

On this Structured Individual analysis, the complement following an aspectual verb is conceptualized as a structured individual, which can be mapped along a variety of dimensions, e.g., spatial, temporal, informational, eventive. Such dimension mapping is done via a set of lexical functions encoded in aspectual verbs; each associated with a specific dimension, e.g., f_{space} , f_{info} , f_{time} .

For example, in (2) “*The prologue begins the book*,” the complement (*the book*) is conceptualized as a structured individual, construed as an axis along the **informational** dimension. On this dimension, the complement refers to a body of informational content (e.g., stories, chapters). The sentence receives a constitutive reading such that the informational content denoted by the subject (*the prologue*) is mapped by the verb’s (*begin*) function (f_{info}) onto the initial subpart of the informational content denoted by the complement (*the book*). Sentence (2) can also be interpreted along the **spatial** dimension, along which the complement refers to a physical entity. The verb’s function (this time, f_{space}) maps the subject denotation to the initial subpart of the structured individual denoted by the complement. The sentence receives a constitutive reading along the spatial dimension, such as: the prologue is printed on the first page of the book as a physical entity. Hence, an AspV sentence can receive multiple dimension interpretations, and the exact interpretation depends on which dimension the structured individual denoted by the complement is construed.

In (3) “*The short announcement finished the conference*,” the structured individual denoted by the complement is construed as an axis along the **eventive** dimension. The sentence receives an interpretation such that the event denoted by the subject (*the short*

announcement) is mapped by the verb (*finish*) to the final subpart of the event denoted by the complement (*the conference*).

Turning back to (1a) *Dave started this CD of classic Jazz hits*. The sentence with an animate subject referent instantiates multiple dimension interpretations between two types of readings. In the agentive reading along the eventive dimension (1b), the complement is conceived as an event in which the subject takes the agent role. In the constitutive reading (1c), the complement refers to a body of informational content along the informational dimension, or a spatial extent along the spatial dimension.

In short, the composition of an aspectual verb and the complement gives rise to multiple dimension representations, resulting in semantic ambiguity. The ultimate sentence interpretation depends on the specific dimension chosen *in context*.

1.2 The Structured Individual Hypothesis (SIH) for processing AspV sentences

The above analysis leads to the Structured Individual Hypothesis for the real-time comprehension of AspV sentences. While AspV sentences are underspecified among multiple dimension representations, the exact sentence interpretation is determined by the specific dimension along which the structured individual denoted by the complement is construed in a given context. Specifically, the processing of any AspV sentence proceeds incrementally as follows, visually presented in Figure 2.

- (A) Exhaustive lexical retrieval: When comprehenders encounter an aspectual verb, all dimension functions encoded in the verb (e.g., f_{space} , f_{info} , f_{time}) are exhaustively retrieved.
- (B) Dimension composition: The semantic composition of an AspV’s lexical functions and its complement, which is construed as an axis along various dimensions, gives rise to multiple dimension representations (Figure 3).
- (C) Resolution of dimension ambiguity in context: The dimension composition results in a semantic ambiguity among multiple representations. Comprehenders will have to determine in context the relevant dimension along which the structured individual is construed, so as to obtain an appropriate interpretation for the sentence.

Figure 2: SIH for processing AspV sentences

Figure 3: Dimension composition of an AspV and its complement

On the SIH, these processes contribute to the additional processing cost associated with AspV sentences observed in previous studies (DiNardo 2015; Katsika et al. 2012; Lai et al. 2016, in press).

How does context come into play in the processing of multiple semantic representations? By (C), contextual information aids disambiguating sentence interpretation. There are, however, two possible functions of context: (i) If context functions to pre-select the exact dimension, the target AspV sentences would be less costly in a context containing biasing contextual information towards one particular dimension than a neutral context. (ii) Notice that *the exhaustive lexical retrieval* (A) and *the dimension composition of the verb and its complement* (B), occur regardless of context. The cost associated with these processes will not be influenced by context. If context only constrains (i.e. narrows down) the relevant dimension(s), rather than pre-selecting one, after multiple dimension representations are composed, AspV sentences might still be costly in a biasing context as in a neutral context.

To better understand the processing of multiple dimension representations and the role of context (i.e. pre-selecting vs. constraining), we examine the pattern of AspV sentences in a biasing context vs. a neutral context.

2. Method

We conducted an eye-movement experiment, placing AspV sentences in a context containing biasing information or without.

2.1. Materials

Thirty sets of passages were created, each consisting of a context sentence followed by a target sentence. Each target sentence contained either an aspectual verb or a psychological verb (e.g., *enjoy*, *love*) that serves as the control condition. Each AspV sentence was paired with three types of context: (i) context that biased towards the agentive reading along the eventive dimension (**eventBiasing-AspV**), (ii) context that based towards the constitutive reading along the informational/spatial dimension (**constBiasing-AspV**), and (iii) context that allowed both the agentive and constitutive readings along multiple dimensions (**Neutral-AspV**). On the other hand, each target sentence with a psychological verb (PsychV) was paired with two types of context: eventBiasing (**eventBiasing-PsychV**) or neutral (**Neutral-PsychV**). PsychV sentences were not paired with the constitutive-biasing context because they do not yield a constitutive reading. In addition, fifty filler sentences were introduced. Table 1 presents a sample set of the five critical conditions.

Table 1: Conditions & Sample sentences

Condition	Context Sentence	Target Sentence
eventBiasing -AspV	<i>Musicians often record their pieces for compilation or memorial albums.</i>	<i>Dave Brubeck started this CD of classic Jazz hits.</i>
constBiasing -AspV	<i>Kevin owns numerous CDs by different Jazz musicians.</i>	
Neutral -AspV	<i>Many musicians have music libraries that contain tons of albums.</i>	
eventBiasing -PsychV	<i>Musicians often record their pieces for compilation or memorial albums.</i>	<i>Dave Brubeck loved this CD of classic Jazz hits.</i>
Neutral -PsychV	<i>Many musicians have music libraries that contain tons of albums.</i>	

The SIH **predicts** that AspV sentences will engender longer reading times (RTs) than the control PsychV sentences, due to the exhaustive lexical retrieval of aspectual verbs and the composition of multiple dimension representations. The effect of context remains a question. If context functions to *pre-select* the exact dimension, preventing the composition of multiple dimension representations, then a context effect would appear early on during the processing of the target sentence. However, if context functions to *constrain* (i.e. narrow down), rather than pre-selecting only one, the available dimension representation(s), comprehenders will compose multiple representations regardless, and the effect of context will not be observed (or at least it would appear slower).

2.2. Participants & Procedures

Fifty-one native speakers of American English between the ages of 18–30 were recruited. The participants were asked to read each passage (Context S + Target S) at their own pace and answer a yes/no comprehension question afterwards for 1/3 of the total 200 trials (30 sets of the 5 conditions plus 50 fillers).

2.3. Data Analysis

Prior to analyses, one participant was excluded because the fixations were outside of the predetermined boundaries of the interest areas for more than ¼ of the trials. We further removed trials that either (a) contained >3 blinks, (b) the total duration was longer than 10 seconds, (c) the first fixation was not at the region containing the subject noun phrase, or (d) was not properly recorded due to experimental errors. In total, 9.029% of the critical trials were removed by these criteria.

For the eye-movement measurements, we focused on three regions of interest: (a) the critical main verb ~ the word prior to the complement head, (b) the complement head and the following word, (c) two content words following the previous region—Region 2~4 in Table 2 below.

Table 2: Example of the three regions of interest—Reg.2, 3, 4

Verb Type	Reg.1	Reg. 2	Reg. 3	Reg. 4	Reg.5
AspV	Dave Brubeck	<i>started</i> this	CD of	classic Jazz	hits.
PsychV	Dave Brubeck	<i>loved</i> this	CD of	classic Jazz	hits.

At each region of interest, we examined four measurement variables: (a) *First-pass duration*, (b) *First-pass regression*—coded dichotomously; 1 if the participants looked back to an earlier region after the first fixation in the region and 0 otherwise, (c) *Regression-path duration*—the sum of all fixation durations from the first fixation in a region before the eyes existed the region, (d) *Second-pass duration*—the sum of all fixation durations that were not the first-pass fixations in the region.

We analyzed these measurement using mixed effects models for either continuous or binominal responses, as appropriate, in the R statistical environment (R Core Team, 2015) using the *lme4* packages. Two sets of analyses were carried out. (1) The first set examined the effect of verb type, context type, and their interaction during comprehension as a 2x2 design: Verb Type (AspV, PsychV) x Context Type (Neutral, eventBiasing). (2) The second set evaluated the effect of context on the processing of AspV sentences, targeting the three conditions: Neutral-AspV, eventBiasing-AspV, constBiasing-AspV. The assessment of any effect was evaluated by

model comparisons with Bonferroni corrections; the critical *p*-value of 0.05 was divided by 12 (3 regions of interest x 4 measurement variables), thresholding at *p*=0.0042.

3. Results

Results of comprehension questions showed 92.79% accuracy; all participants reached 80% accuracy, suggesting that they were focused on the reading task.

The analyses of Verb Type x Context Type revealed a main effect of Verb Type in all regions of interest, such that AspV sentences induced longer reading times (RTs) than PsychV sentences in later measurements. Specifically, the Verb Type effect (AspV > PsychV) was found at Region 2 in second-pass duration, ($\chi^2(1)=29.796$, *p*< .001), Region 3 in first-pass regression ($\chi^2(1)=31.168$, *p*< .001) and second-pass duration ($\chi^2(1)=19.996$, *p*< .001), and Region 4 in regression-path duration ($\chi^2(1)=9.82$, *p*= .0017). No context effect was found, nor any effect of interaction. These were presented in Figure 4~6 (where *n*= the number of participants). On the other hand, the AspV-only analyses yielded no significant results in any measurement at any region, indicating no effect of context type for AspV sentences.

Figure 4: First-pass regression results (mean ± 1 se)

Figure 5: Regression-path duration results (mean ± 1 se)

Figure 6: Second-pass duration results (mean $\pm$ 1 se).

4. Discussion

As predicted, AspV sentences engendered longer RTs than the control sentences. On the SIH, the additional cost associated with AspV sentences results from the exhaustive retrieval of the verb's lexical functions and the semantic composition of multiple dimension representations.

On the other hand, no effect of context facilitation was observed in the regions examined. AspV sentences showed a similar processing profile in a context with biasing information as in a neutral context (i.e. Neutral-AspV $\cong$ eventBiasing-AspV $\cong$ constBiasing-AspV). This suggests that lexical retrieval and the composition of multiple dimension representations are encapsulated from context (*cf.* Shapiro et al. 1989; Swinney 1979). In other words, all lexical functions encoded in aspectual verbs are retrieved, and all dimension representations are composed initially, as this is required as part of the meaning implementation of aspectual verbs. Having a prior biasing context does not prevent the parser from composing multiple semantic representations, and hence does not eliminate the cost associated with this process.

Based on these results, we suggest that the parser retrieves lexical meaning exhaustively and underspecify the dimension representations during real-time processing. The role of context is likely to *constrain*, rather than preselect, the appropriate semantic representation(s), and this occurs only *after* multiple dimension representations are composed.

5. Conclusion

Taken together, this study reveals that in real-time comprehension, (i) composition of sentences with mutually exclusive multiple dimension representations require additional processing effort; and (ii) the exhaustive lexical retrieval and the semantic composition of multiple dimension representations take place regardless of context, (iii) context constrains, rather than pre-selects, the relevant interpretation.

6. Reference

- DiNardo, Laura. 2015. Competing analyses of complement coercion: new evidence from behavioral and electrophysiological methods. Senior thesis.
- Lai, Yao-Ying, Cheryl Lacadie, Todd Constable, Ashwini Deo, and Maria Piñango. In press. Complement coercion as the processing of aspectual verbs: Evidence from Self-Paced Reading and fMRI . In Winter, Y. and Hampton, J. (ed.) *Compositionality and Concepts in Linguistics and Psychology*.
- Lai, Yao-Ying, Cheryl Lacadie, Todd Constable, Ashwini Deo, and Maria Piñango. 2016. The structured individual hypothesis for processing aspectual verbs. *Proceedings of Berkeley Linguistics Society* 42.
- Piñango, Maria Mercedes, and Ashwini Deo. 2015. Reanalyzing the complement coercion effect through a generalized lexical semantics for aspectual verbs. *Journal of Semantics* ffv003.
- R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Shapiro, Lewis P, Edgar B Zurif, and Jane Grimshaw. 1989. Verb processing during sentence comprehension: Contextual impenetrability. *Journal of psycholinguistic research* 18:223–243.
- Swinney, David A. 1979. Lexical access during sentence comprehension:(re) consideration of context effects. *Journal of verbal learning and verbal behavior* 18:645–659