The Structured Individual Hypothesis for processing aspectual verbs

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The Structured Individual Hypothesis for Processing Aspectual Verbs *

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1 Introduction

Aspectual verbs (AspVs) are verbs such as *begin, finish, end, continue.* Sentences with aspectual verbs like (1a), in which an aspectual verb is composed with an entity-denoting complement, often receive an interpretation as in (1b). The subject denotation *Jane* is conceived of as an agent that began doing some activity involving the complement denotation, *the book.* This kind of reading will be called the "agentive reading" of AspV sentences.

(1) a. Jane began the book.
b. ⇝ Jane began reading/writing/... the book.

On the other hand, sentences like (2a) are interpreted as (2b), in which the subject denotation is conceived of as a subpart of the entity denoted by the complement. This kind of reading will be called the "constitutive reading" of AspV sentences.

(2) a. The chapter on global warming began the book.
b. ⇝ The chapter on global warming was the initial subpart of the book.

Examples (1) and (2) demonstrate that sentences with aspectual verbs can give rise to both an agentive reading and a constitutive reading.

In terms of real-time comprehension, it has been shown that sentences with aspectual verbs like (1a) engender additional processing cost and localizable brain activity, as compared to (3), in which an activity is morpho-syntactically present.

(3) Jane read/wrote the book.

The processing cost associated with aspectual verbs and its potential brain correlates have been shown in a variety of measurements in previous studies, including eye-movements (Traxler et al., 2002, 2005; Pickering et al., 2005; Frisson and McElree, 2008; Katsika et al., 2012), self-paced reading (McElree et al., 2001; Traxler et al., 2002), multi-response speed-accuracy trade off paradigm (MR-SAT) (McElree et al., 2006), focal lesion (Piñango and Zurif, 2001), MEG (Pylkkänen and McElree, 2007), ERP (Kuperberg et al., 2010; Baggio et al., 2010), and fMRI (Husband et al., 2011; Lai et al., 2014). However, this cost has only been measured on the basis of the agentive reading.

Two questions emerging from these observations: First, is there a unified way to capture both the agentive and constitutive readings in sentences with aspectual verbs? Second, can such an analysis account for the processing cost associated with these sentences?

The first question has been addressed by Piñango and Deo (2012, 2015), whose structured individual analysis will be introduced below. Based on their analysis, we propose the Structured

*We would like to take this chance to thank the audience of the BLS42 workshop for useful comments.

Individual Hypothesis to address the second question regarding the source of processing cost associated with AspV sentences. This study reports two experiments that test this hypothesis, along with a pretest questionnaire. We show that the results are consistent with the Structured Individual Hypothesis for processing aspectual verbs in both agentive and constitutive readings.

1.1 The Structured Individual Analysis

This section introduces the Structured Individual analysis proposed by Piñango and Deo (2012, 2015). Intuitively, aspectual verbs such as "*begin*" and "*finish*" map the subject denotation to a specific subpart of a structured entity denoted by the complement. For example, in (4), the aspectual verb "*begin*" maps the denotation of "*Boston Common*" to an initial subpart of a structured entity denoted by "*the Freedom Trail*".

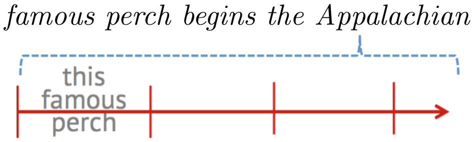
(4) Boston Common begins the Freedom Trail.

Piñango & Deo proposes that aspectual verbs select for structured individuals as their complements. Structured individuals are defined as entities that can be conceptualized as a directed path structure—an *axis*—in some ontological dimension.

(5) *Directed path structure*

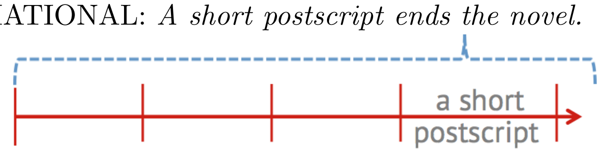
The notion of "dimension" can be illustrated by the following examples. Consider this sentence: (6) "*This famous perch begins the Appalachian Trail.*" The complement denotation ("the Appalachian Trail") is conceptualized as a structured individual, which is construed as an axis along the **spatial dimension**. The verb "*begin*" maps the subject denotation "this famous perch" onto the initial subpart of the axis construed by the complement: that is, the spatial extent of the famous perch is the initial subpart of the spatial extent of the Appalachian Trail, as visualized in (6) below. This sentence exemplifies the constitutive reading along the spatial dimension.

(6) SPATIAL: *This famous perch begins the Appalachian Trail.*



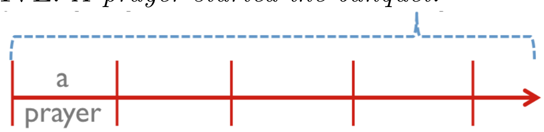
Sentence (7) "*A short postscript ends the novel.*" exemplifies the constitutive reading along the **informational dimension**. In this case, the complement "*the novel*" is conceptualized as a structured individual, constructed as an axis along the informational dimension. The aspectual verb "*ends*" maps the subject denotation, "a short postscript," onto the final subpart of this axis: that is, the informational content denoted by "*a postscript*" is the final subpart of the content denoted by "*the novel.*"

(7) INFORMATIONAL: *A short postscript ends the novel.*



The dimension can also be **eventive**. For instance, the complement in the following sentence is conceptualized as a structured individual, construed as an axis along the eventive dimension. Here, the aspectual verb maps "*a prayer*" onto the initial subpart of the axis denoted by "the banquet." Sentence (8) exemplifies a constitutive reading along the eventive dimension, such that the praying event is the initial event of a (macro-)event denoted by "the banquet."

(8) EVENTIVE: *A prayer started the banquet.*



Examples (6)∼(8) demonstrate that a structured individual denoted by the complement following an aspectual verb can be realized along various dimensions. The sentence is interpreted in accordance with the dimension onto which the structured individual is construed as an axis.

In addition, Piñango and Deo (2015) argue that the functions that map the complement denotation to an axis along a specific dimension are lexically encoded as part of the meaning of aspectual verbs. Each lexical function is associated with a specific dimension (e.g. f_{space}, f_{time}, f_{info}). That is, f_{space} maps the structured individual denoted by the complement onto the spatial dimension, and f_{info} maps the structured individual denoted by the complement onto the informational dimension.

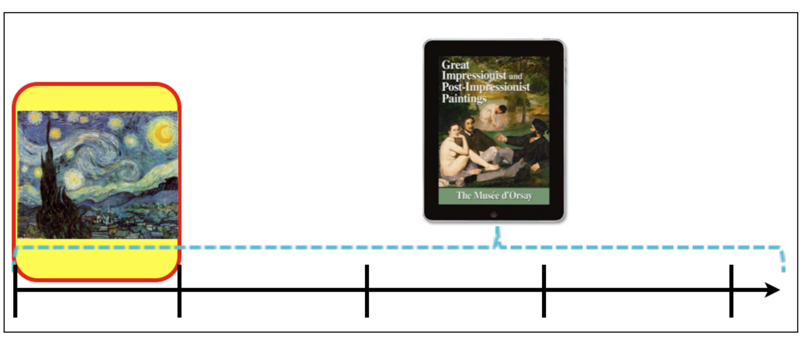
This means that the interpretation of an AspV sentence depends in large part on the dimension along which the structured individual is construed. Crucially, the choice of dimension is contextually determined; this will be explained in more detailed below.

1.1.1 Two configurations in which aspectual verbs appear

Closer examination, AspVs can be composed with an animate subject (e.g., (1a)) or with an inanimate subject (e.g., (2a)).

In the case in which an aspectual verb combines with a subject that denotes an *inanimate* entity, such as "*'Starry Night' began the collection of oil paintings*," the sentence gives rise to a constitutive reading which can be schematized as below. Such configurations (inanimate subject + AspV) will be termed the "AspVinanimate" configuration henceforth.

(9) "Starry Night" began the collection of oil paintings.



Notice that this constitutive reading is itself underspecified with respect to the dimension along which the complement denotation might be construed as a structured individual. If the complement is construed as an axis along the *spatial* dimension, "*the collection of oil paintings*" is conceived as a physical entity, such as a book consisting of X pages. Along this spatial dimension, the subject denotation "Starry Night" is printed on the first page of this collection. If the complement is construed along the *informational* dimension, it will be conceived as a structured body of informational content, consisting of X paintings, where each painting is a piece of informational content. Accordingly, the sentence is understood to convey that the painting titled "Starry Night" was the first painting of this collection. In other words, a constitutive reading of an AspV sentence can be realized along multiple dimensions, yielding different interpretations.

On the other hand, when an aspectual verb combines with a subject that denotes an *animate* entity, such as (10), the sentence gives rise to a semantic ambiguity between an agentive and a constitutive reading along various dimensions. Such configurations will be termed the "AspVanimate" configuration henceforth.

(10) Van Gogh began the collection of oil paintings.

Sentence (10) can give rise to an agentive reading, such as *Van Gogh began browsing/editing/etc. the collection of oil paintings.* In this case, the complement is conceptualized as a structured individual, construed as an axis along the eventive dimension, and the subject is conceived as an Agent[1]. The sentence can also give rise to a constitutive reading, such as *Van Gogh's painting was the initial subpart of the collection.* Just as the constitutive reading in the inanimate configuration, here the complement can be realized along different dimensions. It can be conceived as a physical entity along the spatial dimension (e.g., a book consisting of X pages), or as a structured body of informational content along the informational dimension (e.g., a collection of X paintings). In this sense, the composition of an aspectual verb and an animate subject engenders a semantic ambiguity between an agentive reading and a constitutive reading. The exact interpretation of the sentence depends on the dimension along which the structured individual (denoted by the complement) is construed.

Importantly, on the current analysis, both AspVanimate and AspVinaninate configurations involve dimension ambiguity. The complement, and the sentence accordingly, can be interpreted along more than one dimension (e.g., spatial, information, eventive, temporal).

1.1.2 Factors that determine the interpretations of AspV sentences

The Structured Individual analysis identifies two factors that influence the reading of sentences with aspectual verbs: (a) the composition with the subject, and (b) the choice of dimension.

(11) *Two factors affecting the interpretations of AspV sentences*

(a) Composition with Subject	(b) Choice of Dimension	⇒ Reading
Animate entity	Eventive Spatial	Agentive reading
Inanimate entity	Informational Temporal	Constitutive reading

The composition of an aspectual verb with an animate subject does not necessarily give rise to an agentive reading along the eventive dimension. For instance, the sentence "*The little boy began the line*," which contains a subject that is typically conceived as an animate entity, engenders a constitutive reading along the spatial dimension.

In addition, the eventive dimension by itself does not predict an agentive reading, in which the subject is conceived of as an agent. For instance, the sentence "*The prayer finished the banquet*"

[1] Please see Piñango and Deo (2015) for details.

is interpreted along the eventive dimension, yet it gives rise to a constitutive reading. Here the subject ("*the prayer*") denotes an event, and the complement denotes an ordered set of subevents of the banquet event. The sentence is understood to convey that the praying event was the final subevent of the larger event denoted by "*the banquet.*" More examples are given below.

(12) *The interaction between Subject animacy X Dimension*

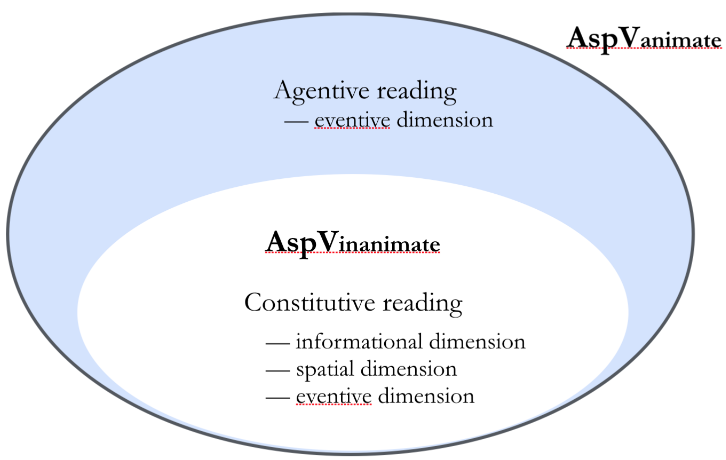
Composition with Subject	**Dimension**	Reading	Example
Animate Subj + AspV	eventive	agentive	*Van Gogh*$_{(agent)}$ *began the collection.*
	informational	constitutive	*Van Gogh*$_{(content)}$ *begins the collection.*
	spatial		*The little boy began the queue.*
Inanimate Subj + AspV	eventive	agentive	*The printer started my paper.*
		constitutive	*The prayer finished the banquet.*
	informational		*A short postscript ends the novel.*
	spatial		*The famous perch begins the trail.*
	temporal		*The December solstice begins the winter.*

These indicate that subject animacy or dimension alone cannot determine the type of reading. Rather, the interpretation of an AspV sentence is determined by both factors, (a) and (b) listed above, in combination.

1.1.3 The superset relationship between the two configurations of AspV sentences

Recall the two configurations of AspV sentences mentioned in Section 1.1.1. The composition of an aspectual verb and an inanimate subject (AspVinanimate) gives rise to a constitutive reading along various dimensions. With an animate subject, an AspV sentence (AspVanimate) also gives rise to a constitutive reading along multiple dimensions. In addition, it can yield an agentive reading along the eventive dimension. That is, the set of dimensional readings available in the AspVanimate configuration is a superset of those available in the AspVinanimate configuration: AspVanimate ⊇ AspVinanimate, in terms of available dimensional interpretations.

(13) *Superset relationship: AspVanimate ⊇ AspVinanimate*



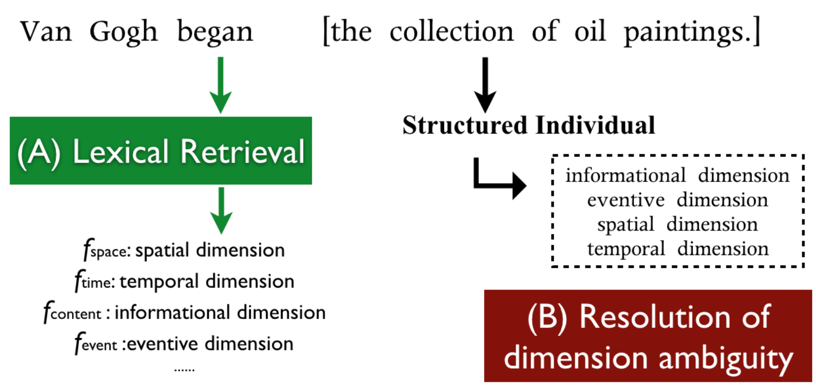
The Structured Individual analysis suggests that sentences with aspectual verbs are semantically ambiguous among various dimensions. Comprehenders must determine the specific dimension in context to get the exact interpretation. This analysis provides a unified way to capture both the agentive and constitutive readings of sentences with aspectual verbs. With this analysis in place, we address the question of the real-time comprehension—predictions that follow from the analysis.

1.2 The Structured Individual Hypothesis

The question we ask here is: Can the above semantic analysis account for the processing cost associated with sentences with aspectual verbs? We answer this question by the processing implication of the Structured Individual analysis. The analysis and its processing implications is what constitute the Structured Individual Hypothesis. Specifically, we propose that the real-time comprehension of an AspV sentence proceeds as below: When comprehenders encounter an aspectual verb, they retrieve all lexical functions encoded in the verb; each function is associated with a specific dimension (e.g. spatial, informational, temporal, eventive). Recall that aspectual verbs require their complement to be conceptualized as a structured individual. When comprehenders encounter the complement, the structured individual denoted by the complement is construed as an axis along a variety of dimensions. Hence, comprehenders have to determine *in context* the relevant dimension along which the structured individual is construed, in order to obtain an appropriate interpretation for the sentence.

According to this Structured Individual Hypothesis, processing sentences with aspectual verbs requires more effort because it involves (A) retrieval of dimension-functions in aspectual verbs, and (B) resolution of dimension ambiguity (i.e., choosing the contextually-relevant dimension) during the composition with the complement.

(14) ***The Structured Individual Hypothesis***



It should be noted that, in addition to the generalized semantic representation for both agentive and constitutive readings, there is experimental evidence that supports treating aspectual verbs as a unified group distinct from other verb types. Katsika et al.'s (2012) eye-tracking study reveals that the set of verbs used in previous studies that investigate the cost associated with sentences like (1a) in fact collapses aspectual verbs (e.g. *begin, finish*) with psychological verbs (e.g. *enjoy, endure*). Their results show that aspectual verbs engendered longer reading times than psychological verbs. The dissociation between these two verb types is further suggested by Utt et al. (2013). Recently, Lai et al. (2014) explicitly test the Structured Individual Hypothesis. Their results show that processing aspectual verbs not only requires more effort in real-time comprehension, as found in Katsika et al. (2012), but also involves localizable brain regions.

The present study extends Lai et al.'s study by introducing a condition in which an aspectual verb is composed with an inanimate subject, i.e. the AspVinanimate configuration in Section 1.1.1. If the Structured Individual Hypothesis is on the right track—that is, all AspV sentences involve retrieval of lexical functions and dimension ambiguity—then both the AspVanimate and AspV-inanimate configurations should pattern alike regardless of subject animacy. Both are predicted to be costly. The condition with an inanimate subject also allows to investigate the factors that determine the reading of AspV sentences according to the hypothesis; namely, subject animacy and the choice of dimension in combination (not just animacy alone).

To test this hypothesis, we conducted a self-paced reading experiment (Exp.1) and an fMRI experiment (Exp.2) to investigate the behavioral patterns and neurological correlates associated with processing aspectual verbs, along with a questionnaire pretest.

2 Pretest: Rating questionnaire

We first employed a rating questionnaire to make sure that the stimuli which will be used in the following experiments are acceptable to native speakers.

2.1 Methods

2.1.1 Conditions & Materials

We created four conditions. The first two conditions contained sentences with aspectual verbs and entity-denoting complements. The subject in the first condition typically refers to an animate entity (AspVanimate), while the subject in the second condition typically refers to an inanimate entity (AspVinanimate). These two AspV conditions were contrasted with two control conditions with psychological verbs, such as "*enjoy, endure*" (Control$_{PsychV1}$) and "*love, hate*" (Control$_{PsychV2}$). The first set of control-psychVs have been investigated in previous studies while the second set of control-psychVs have not. We do not distinguish these two conditions; both serve as controls.

(15) *Conditions and sample sentences*

Condition		Verb	Comp.-head	Comp.+1	Comp.+2	
AspVinanimate	***"Starry Night"***	***starts***	*the collection*	*of*	*impressionist*	*oil paintings.*
AspVanimate	***Van Gogh***	***started***	...	...	...	...
Control$_{PsychV1}$	*Van Gogh*	***enjoyed***	...	...	...	...
Control$_{PsychV2}$	*Van Gogh*	***loved***	...	...	...	...

Fifty quadruples of the four conditions were created and one hundred fillers were introduced, yielding a total of three hundred sentences.

2.1.2 Participants & Procedures

Forty participants were recruited, all were native speakers of American English, between the ages of 18-30 and without reading disabilities. Their tasks were to rate the acceptability of each sentence from a scale $1 \sim 5$ and answer a comprehension question afterwards on a computer screen (5=makes sense; 1= does NOT make sense).

2.2 Results

We performed the Analysis of Variance (ANOVA), using subject as a random factor and rating score as a fixed factor. The data of three participants were discarded because their responses were either undifferentiated or inconsistent. Result showed that all sentences in the four conditions are within the acceptable range (> 3.7).

(16) *Results of sensicality rating (N=37)*

Condition	Mean	SD (Standard Deviation)	SE (Standard Error)
AspVanimate	4.13	0.75	0.04
AspVinanimate	3.73	0.84	0.05
$\text{Control}_{PsychV1}$	4.31	0.52	0.04
$\text{Control}_{PsychV2}$	4.80	0.23	0.02

3 Experiment 1: Self-Paced Reading

To investigate the time-course of the cost associated with processing AspV sentences, we conducted a self-paced reading experiment with the moving-window paradigm.

3.1 Method

3.1.1 Materials

The quadruples of the four manipulating conditions were adopted from the pretest rating questionnaire. A set of unacceptable sentences was introduced as fillers. Each sentence was segmented into several windows, shown as the cells of Table (15). Our windows of interest were the verb, the complement head, and the two segments following the complement head (Complement+1, Complement+2).

3.1.2 Participants

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

3.1.3 Procedures

Sentences were visually presented segment-by-segment on a computer screen. The participants were instructed to read the sentences at their own pace. Every trial began with a series of dash lines corresponding to the words of the sentences on the screen, with a plus sign appearing on the left of the first segment, signaling the beginning of the sentence. The participants began by pressing the spacebar, causing the first segment to show up. With the subsequent pressing, the next segment appeared, and the previous segment was replaced by a set of dashes. At the end of the sentence, the participants were queried a comprehension question. A practice session was given beforehand, in which the participants had to reach 80% accuracy before proceeding to real trials.

3.2 Data Analysis

We performed a mixed model analysis, incorporating a fixed effect of condition (4 levels: the four conditions), and random intercepts for both subject and item. The data of all 28 participants were taken into account in data analysis. The reading times (RTs) measurements of the four windows of interest were analyzed: verb, complement head, and the two segments following the complement head (Complement+1, Complement+2). Analyses were carried out in the R statistical environment, using the *lmer* function in the *lme4* packages. (Baayen et al., 2008; R Core Team, 2014). For the condition effect of RTs, we contrasted a model with condition as the predictor agains a null model without it. Pair-wise comparisons were corrected by Tukey tests for p-values. All significant contrasts are reported.

3.3 Results

The accuracy of the comprehension task was 95.03%, indicating that the participants fully comprehended the sentences and paid attention during the reading task.

No significant effect was found at the Verb or the Complement head position. The Verb segment showed a marginal effect of condition, yet it did not reach significance ($\chi^2(3)= 7.20$, $p< .066$) and disappeared at the following complement head position.

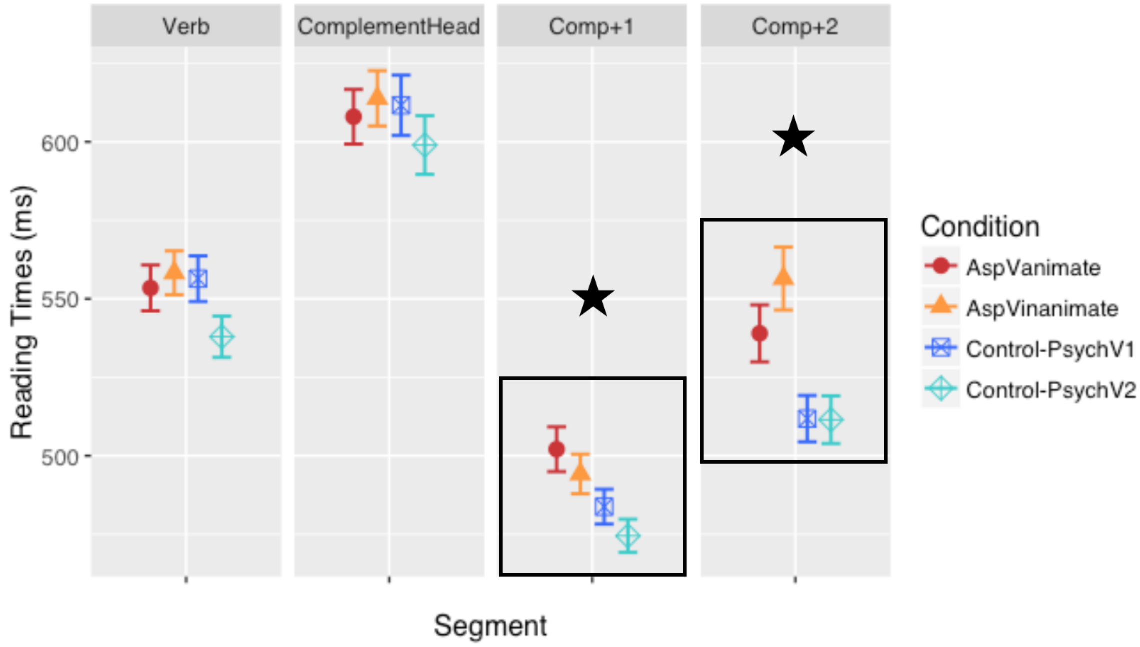
A significant effect of condition appeared at Complement+1 position ($\chi^2(3)= 15.37$, $p= .0015$). At this segment, both the AspVanimate and AspVinanimate conditions showed significantly longer RTs than the control condition: AspVanimate > $\text{Control}_{PsychV2}$ (b=27.58, $p= .0015$), AspVinanimate > $\text{Control}_{PsychV2}$ (b=19.70, $p= .0438$).

The Complement+2 segment revealed a similar pattern. A significant effect was found ($\chi^2(3)=$ 29.04, $p < .001$). At this segment, pair-wise comparisons showed that the two conditions with aspectual verbs engendered significantly longer RTs than the two control conditions. Specifically, AspVanimate > $\text{Control}_{PsychV1}$ (b= 27.17, $p= .03$); AspVanimate > $\text{Control}_{PsychV2}$ (b= 27.50, $p= .03$); AspVinanimate > $\text{Control}_{PsychV1}$ (b= 44.63, $p< .001$); AspVinanimate > $\text{Control}_{PsychV2}$ (b= 44.97, $p< .001$). The two AspV conditions did not differ from each other, neither did the two control PsychV conditions.

(17) *Results of reading times (in milliseconds), standard errors in parentheses*

Condition	Verb	Complement Head	Complement+1	Complement+2
AspVanimate	553.45 (7.30)	608.01 (8.70)	502.08 (7.13)	538.99 (9.07)
AspVinanimate	558.28 (6.98)	613.86 (8.81)	494.20 (6.29)	556.45 (10.01)
$\text{Control}_{PsychV1}$	556.42 (7.26)	611.64 (9.61)	438.78 (5.55)	511.82 (7.38)
$\text{Control}_{PsychV2}$	537.93 (6.58)	598.98 (9.34)	474.50 (5.28)	511.49 (7.59)

(18) *Results of reading times (in milliseconds)*



Overall, results of RTs show that all sentences with aspectual verbs engendered longer RTs than the control sentences with psychological verbs, at the two segments following the complement head noun. Importantly, the two AspV conditions patterned alike, regardless of the difference in subject animacy. This is consistent with the Structured Individual Hypothesis, which claims that all sentences with aspectual verbs involve semantic ambiguity along multiple dimensions. Processing AspV sentences is more costly because comprehenders have to resolve dimension ambiguity, presumably by searching contextual information, in order to obtain a specific interpretation for the sentence.

4 Experiment 2: fMRI

Next, we conducted an fMRI experiment to investigate the neural correlates associated with processing sentences containing aspectual verbs.

4.1 Method

4.1.1 Materials

The fifty quadruples (200 sentences) remained the same as the self-paced reading experiment, with a different set of 100 filler sentences introduced. The whole set of stimuli consisted of 300 sentences in total. Each participant saw all 300 sentences.

4.1.2 Participants

Sixteen native speakers of American English were recruited for this study, all between the ages of 18-30, right-handed, without any reading disability or history of neurological disorders.

4.1.3 Paradigm

The set of 300 sentences were divided into 10 runs; each run contained 30 sentences, lasting 5 minutes 33 seconds with the inclusion of device connection delay. Within each run, the sentences were pseudo-randomized such that no successive sentences were of the same condition.

Each sentence was visually presented segment-by-segment by E-Prime software, as in the self-paced reading experiment; each segment lasted for 500 ms. The participants received a comprehension question after the sentence; each question remained on the screen for 4000 ms. There was a 500 ms interval between the sentence-final word and the question.

4.1.4 Imaging Acquisition

Anatomical Measurements: The fMRI experiment was carried out on a Siemens Sonata; 3T whole body MRI scanner. Each session began with a 3-plane localizer followed by a sagittal localizer, and an inversion recovery T1 weighted scan (TE/TR=2.61/285 ms, matrix 192x192, FOV=220 mm, flip angle=70 degrees, bandwidth = 501 Hz/pix, 51 slices with 2.5mm thickness). The AC-PC (anterior and posterior commissure) line was defined by this acquisition for prescription of the anatomic T1 images and functional images in the following series.

Functional Measurements During the task, we conducted event-related functional MRI using gradient echo echo-planar imaging (EPI) blood oxygenation level dependent (BOLD) contrast, with TE =30 ms, TR=956 ms, matrix 84 x 84, FOV=210mm, flip angle=62 degrees, bandwidth=2289 Hz/pixel, slice thickness=2.5 mm, with 321 measurements (images per slice). The scanner was set to trigger the stimulus presentation program, which enabled the image acquisition to be synchronized with the stimulus presentation.

At the end of the functional imaging, a high-resolution 3D Magnetization Prepared Rapid Gradient Echo (MPRAGE) was used to acquire sagittal images for multi-subject registration, with TE=2.77 ms, TR=2530 ms, acquisition matrix 256x256, FOV=256mm, bandwidth = 179 Hz/pix, flip angle=7 degrees, 176 slices with slice thickness=1mm. The fMRI data within subjects was registered to this brain volume, which was then registered across subjects into a common 3D brain space by the Yale BioImage Suite software package (Papademetris et al., 2006).

4.2 fMRI Data analysis (Event-related)

All data were converted from Digital Imaging and Communication in Medicine (DICOM) format to analyze format using XMedCon (Nolfe et al., 2003). During the conversion process, the first 6 images at the beginning of each of the 10 functional runs were discarded to enable the signal to achieve steady-state equilibrium between radio frequency pulsing and relaxation, leaving 315 images per slice per run for analysis. Functional images were motion-corrected with the Statistical Parametric Mapping (SPM) 5 algorithm (www.fil.ion.ucl.ac.uk/spm/software/spm5) for three translational directions (x, y, z) and three possible rotations (pitch, yaw, roll). Trials with linear motion that had a displacement exceeding 1.5 mm or rotation exceeding 2 degrees were rejected. The data from one participant were excluded because of severe head movement. All further analyses were performed using BioImage Suite (Papademetris et al., 2006).

Individual subject data was analyzed using a General Linear Model (GLM) on each voxel in the entire brain volume with regressors specific for each task. In data analysis, each sentence was segmented into two events (i.e., two regressors), which correspond to the two hypothesized processes involved in the real-time comprehension of AspV sentences. **Event 1** included the onset of the subject noun phrase until the offset of the main verb. During this time window, readers were hypothesized to exhaustively activate the dimension-associated functions lexically encoded in aspectual verbs. **Event 2** included the onset of the complement noun phrase until the offset of the sentence-final word. During this time window (i.e. after encountering the complement), readers were hypothesized to resolve dimension ambiguity so as to determine the dimension along which the complement is construed as an axis.

(19) *Event segmentation in fMRI data analysis (cells representing the stimuli presentation)*

Condition	**Event 1 (Subject + Verb)**		**Event 2 (Complement ∼ Sentence-final)**			
AspVinanimate	*"Starry Night"*	*starts*	*the collection*	*of*	*impressionist*	*oil paintings.*
AspVanimate	*Van Gogh*	*started*	...	...	...	...
$\text{Control}_{PsychV1}$	*Van Gogh*	*enjoyed*	...	...	...	...
$\text{Control}_{PsychV2}$	*Van Gogh*	*loved*	...	...	...	...

The resulting beta images for each task were spatially smoothed with a 6 mm Gaussian kernel to account for variations in the location of activation across subjects. The output maps were normalized beta-maps, which were in the acquired space (2.5mm x 2.5mm x 2.5mm).

To take these data into a common reference space, three registrations were calculated within the Yale BioImage Suite software package. The first registration performed a linear registration between the individual subject raw functional image and that subjects 2D anatomical image. The 2D anatomical image was then linearly registered to the individuals 3D anatomical image. The 3D differs from the 2D in that it has a 1x1x1 mm resolution whereas the 2D z-dimension is set by slice-thickness and its x-y dimensions are set by voxel size. Finally, a non-linear registration was computed between the individual 3D anatomical image and a reference 3D image. The reference brain used was the Colin27 Brain Holmes et al. (1998) in Montreal Neurological Institute (MNI) space (Evans et al., 1993). All three registrations were applied sequentially to the individual normalized beta-maps to bring all data into the common reference space.

Data were corrected for multiple comparisons by spatial extent of contiguous suprathresholded individual voxels at an experiment-wise $p < .05$. In a Monte Carlo simulation within the AFNI software package and using a smoothing kernel of 6mm and a connection radius of 4.33mm on 2.5mm x 2.5mm x 2.5mm voxels, it was determined that an activation volume of 183 original voxels (4953 microliters) satisfied the $p < .05$ threshold. Clusters were created for each of the subtractions. Each cluster was identified with a region label, and then associated with additional numeral labels corresponding to Brodmann areas.

4.3 Results

4.3.1 Behavioral Results

The comprehension task showed 88.6% in accuracy. With respect to the response times, we performed a repeated measure ANOVA and found no significant effect of condition. Results of behavioral results were presented below.

(20) *Response times (ms) to the questions in Exp.2*

Conditions	Mean	SD	se
AspVanimate	1684.18	590.90	25.06
AspVinanimate	1685.85	595.22	25.57
$\text{Control}_{PsychV1}$	1722.11	582.23	25.08
$\text{Control}_{PsychV2}$	1651.49	547.17	24.09

4.3.2 Imaging Results

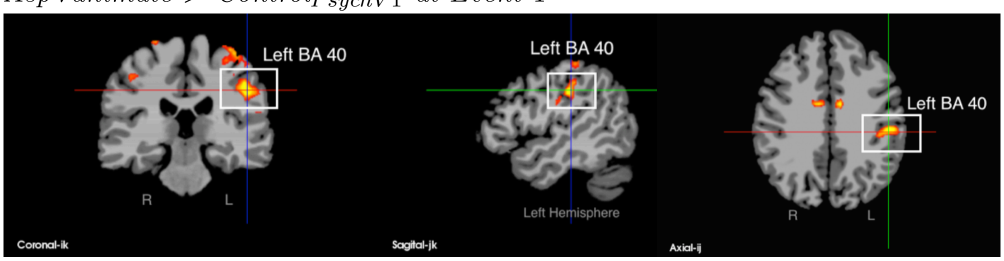
At Event 1 (Subject+Verb), results showed that the AspVanimate condition preferentially recruited left Brodmann Area (BA) 40, which is part of Wernicke's area, over the $\text{Control}_{PsychV1}$ condition. Other regions activated by AspVanimate in this comparison included bilateral BA 6, 24, 7, and primary sensory area.

At Event 2 (Complement∼Sentence-final), the AspVanimate condition preferentially recruited left inferior frontal gyrus (LIFG), including BA 44, 45, 47, and left insula, as compared to the $\text{Control}_{PsychV2}$ condition. Other activated regions for the AspVanimate condition over $\text{Control}_{PsychV2}$ included bilateral BA 6, right BA 8, right IFG, and primary visual cortex. The AspVinanimate condition showed a similar pattern, recruiting LIFG (BA 44, 45, 47) and left insula at Event 2, as compared to the $\text{Control}_{PsychV2}$ condition.

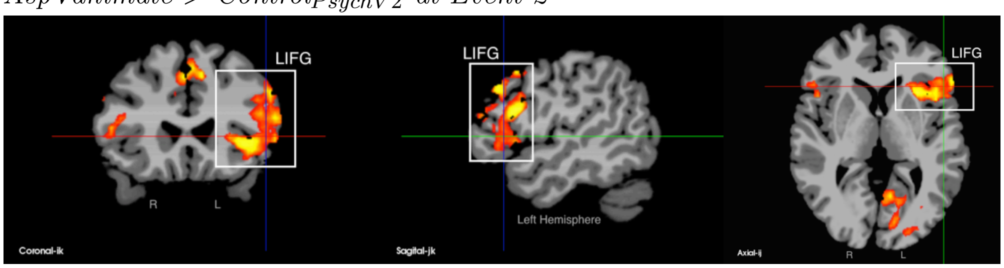
In addition, results at Event 2 revealed that, compared to the AspVinanimate condition, the AspVanimate condition preferentially recruited more activity in bilateral posterior areas (BA 17, 18, 19), bilateral BA 7, left BA 39, 31, and left BA 6, 24.

In sum, the AspVanimate condition engender more Wernicke's activation than the $\text{Control}_{PsychV1}$ at Event 1, while both AspVanimate and AspVinanimate involved LIFG and left insult at Event 2. Besides the shared activation pattern, the brain regions recruited for the AspVanimate condition formed a superset of those recruited for the AspVinanimate condition.

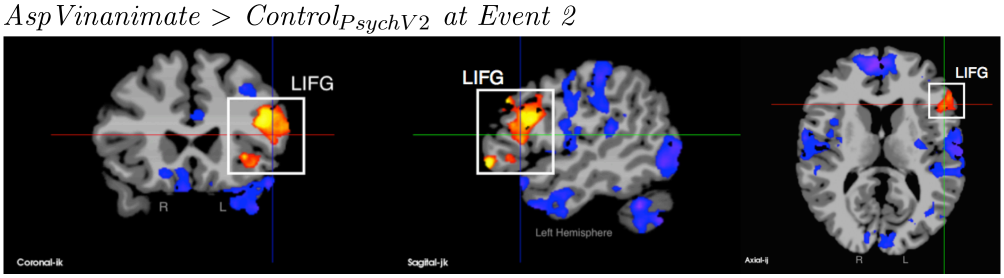
(21) *AspVanimate* $>$ *$\text{Control}_{PsychV1}$ at Event 1*



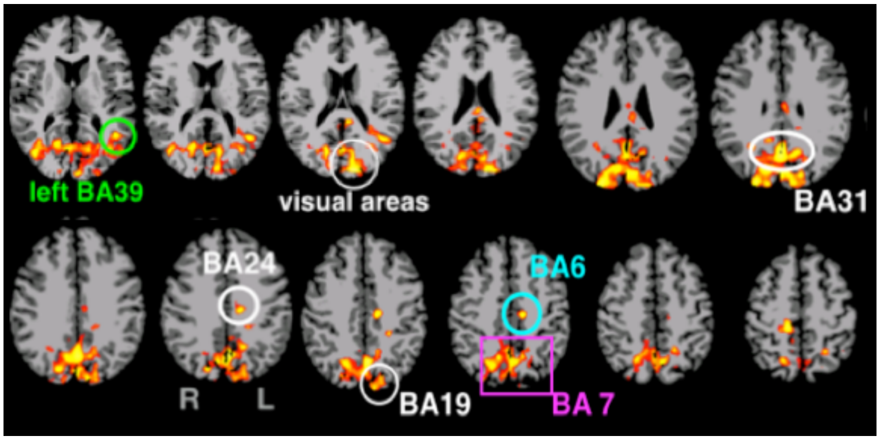
(22) *AspVanimate* $>$ *$\text{Control}_{PsychV2}$ at Event 2*



(23) *AspVinanimate* $>$ *$\text{Control}_{PsychV2}$ at Event 2*



(24) *AspVaniamte > AspVinanimate at Event 2*



5 Discussion

We summarize the results as below. First, Experiment 1 (Self-paced reading) showed that sentences with aspectual verbs, including both the AspVanimate and AspVinanimate conditions, induced longer RTs than the control psychological verbs. Experiment 2 (fMRI) revealed that both AspV conditions preferentially recruited LIFG and left insula after the complement was encountered. We take these to reflect the process of resolving dimension ambiguity induced by aspectual verbs. Both behavioral and neurological patterns suggest that all sentences with aspectual verbs, regardless of subject animacy, are processed in a similar way.

These findings are captured by the Structured Individual Hypothesis. It indicates that aspectual verbs require their complement to be a structured individual, which can be construed as an axis along multiple dimensions (e.g. spatial, informational, eventive, temporal). Processing AspV sentences involves (A) retrieval of dimension-function, which maps the complement denotation to a specific axis, encoded in these verbs, and (B) resolution of dimension ambiguity after encountering the complement.

Second, the imaging data suggest that processing sentences with aspectual verbs involved left BA40 (part of Wernicke's area) for exhaustive retrieval of lexical functions, and LIFG for resolution of dimension ambiguity.

Third, the fMRI results revealed a superset relation in terms of brain activity between the two AspV configurations. The regions recruited by the AspVanimate configuration form a superset of those recruited by the AspVinanimate configuration (AspVanimate $\supseteq$ AspVinanimate). While the AspVinanimate configuration yield a constitutive reading along the spatial/informational/temporal/etc. dimension, the AspVanimate configuration can yield an agentive reading along the eventive dimension *in addition*.

The finding that both AspV conditions patterned alike suggest that subject animacy alone does not determine the reading for sentences with aspectual verbs, as mentioned in the Introduction. Animacy is not an ideal indicator for associating semantic arguments, as it cuts across several thematic roles in the semantic representations of predicates. Levin and Hovav (2005, p.173) note that animacy "imposes a rather course-grained ranking, since NPs bearing the agent, experiencer, benefactive, and recipient roles, for instance, are all typically animate."

In our case, an animate subject plays different roles in the agentive versus constitutive reading of AspV sentence; it serves as an Agent in the former and a Theme in the latter. Subject animacy is not associated with a specific reading for AspVanimate sentences; these sentences can give rise to a constitutive reading just like the AspVinanimate configuration. In other words, with respect to the constitutive reading, the subjects in AspVanimate and AspVinanimate function the same. Besides, the subjects in the AspVanimate and PsychV conditions are dissimilar in other semantic features, indicating that animacy alone does not determine sentence interpretation.

(25) *The role of the animate subject & associated readings*

	Subject Animacy	Thematic Role of subject
$\text{AspVanimate}_{-AgentveReading}$	animate	Agent
$\text{AspVanimate}_{-ConstitutiveReading}$	animate	Theme? (¬Agent, ¬Experiencer)
PsychV	animate	Experiencer

Instead of animacy, we suggest that the notion of "control" is a more reliable feature that captures the pattern of the readings in question. A subject bearing the [+control] feature has full control over his/her behavior and the resulting situation denoted by the predicate (Rozwadowska, 1989)[2]. An AspV sentence yields an agentive reading with a [+control] subject, and a constitutive reading with a [−control] subject. As shown in the following table, the control feature of the subject lines up with the two readings of AspV sentences.

(26) *Subject control and sentence interpretation*

	Subject Control	Reading
AspVanimate	[+control]	Agentive
AspVanimate AspVinanimate	[−control]	Constitutive

The control feature not only distinguishes the two readings of AspV sentences but also differentiates between AspV and PsychV sentences. The subject of sentences with the agentive reading seems to have more control ability than the subject of PsychV sentences. We may employ the "*What X do is.....*" test to diagnose volitional involvement in some action (Dowty, 1991; Culicover and Jackendoff, 2005), which is associated with control .

(27) a. AspVanimate-Agentive reading :
✓ What John *(as an actor)* did was begin the book.

b. AspVanimate-Constitutive reading :
*What John *(as a story character)* did was begin the book.

c. AspVinanimate-Constitutive reading :
*What the short prologue did was begin the book.

d. PsychV: What John did was {?enjoy/*love} the book.

As the above test reveals, only the subject of AspV sentences in the agentive reading bears the [+control] feature unequivocally.

Control is often connected with volitionality. For instance, the force-dynamic approach (Talmy, 1988; Croft, 2012) argues that the notion of Agent can be defined as an antagonist that has volitional intrinsic force tendency. Dowty (1991) lists the involvement of volition as a contributing

[2] Rozwadowska (1989) indicates that "Agent is in full control of what he is doing."

properties of her Agent Proto-Role. Jackendoff (1992, p.129) suggests the feature [±volitional] as one characteristic of Agent as "volitional Actor"[3]. Here we do not postulate a fundamental difference between the two, as an entity that has control over his/her behavior is typically volitional in performing the action. Using Jackendoff's test for volitionality—compatibility with *deliberately* (volitional) and *accidentally* (non-volitional)—we observe that [+volition] is most compatible with the agentive reading of AspV sentences, a pattern similar to [+control].

(28) a. AspVanimate-Agentive reading :
✓ The man *(as an actor)* began the book *deliberately.*

b. AspVanimate-Constitutive reading :
? The man *(as a character)* began the book *accidentally.*

c. AspVinanimate-Constitutive reading :
*The long prologue begins the book *deliberately/accidentally.*

d. PsychV: *?*The man enjoyed the book {*deliberately/accidentally*}.

The case of aspectual verbs suggests that this notion of control factors in how comprehenders interpret the sentences.

6 Conclusion

This study examines the Structured Individual Hypothesis for the processing of sentences with aspectual verbs, by specifically contrasting the two configurations of the AspV sentences: those containing an animate-denoting subject and those with an inanimate-denoting subject. Results show that all sentences with aspectual verb, regardless of subject animacy, engendered similar patterns in terms of reading times (self-paced reading) and cortical recruitment (fMRI). Furthermore, we suggest that the feature of control, not animacy, better captures the agentive versus constitutive reading of AspV sentences.

These findings are consistent with the Structured Individual Hypothesis. During real-time comprehension, readers retrieve the lexical functions encoded in aspectual verbs and determine the relevant dimension along which the sentence is to be interpreted. The fact that AspV sentences in the agentive and constitutive readings are processed in a similar way supports a unified analysis for aspectual verbs.

[3]For Jackendoff, Agent could be a doer of action, a volitional actor, or an extrinsic instigator.

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