The Behavioral and Neural Correlates of Silent Causativity in Verbs

Lisa Levinson (Oakland University) & Jonathan Brennan (NYU)
levinson @oakland.edu  jon.brennan@nyu.edu

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The (Silent) Causative/Inchoative Alternation in English

Same verb, different meanings:
1) The ice **melted**.  (inchoative)
2) The sun **melted** the ice.  (causative)

Simplified semantic representations:
1) **BECOME** melted(\textit{the ice})
2) \textit{the sun} **CAUSE** **BECOME** melted(\textit{the ice})

Puzzle:
How is the CAUSE meaning represented?
Aims of this Study

- Derive processing predictions from theoretical hypotheses regarding the representation of English zero-derived causatives.
- Test these hypotheses behaviorally.
- Further tease apart the behavioral results by investigating the neural correlates of any observed processing costs.
- Establish a behavioral and neural profile for zero-derived causatives which can be compared with other alternations in English and other languages.
Deriving Processing Predictions
Morphological Alternation in Other Languages

Separate Derivation in Walpiri (Hale and Keyser 1998: 93)
1) wiri-jarri- ‘become large’
2) wiri-ma- ‘cause to become large’

Anticausativization in O’odham (Hale and Keyser 1998: 97)
3) `e-mul ‘become broken’
4) mul ‘cause to become broken’

Causativization in O’odham (Hale and Keyser 1998: 92)
5) weg-i ‘become red’
6) weg-i-(ji)d ‘cause to become red’
Morphosyntactic Hypotheses for English

- **Separate Derivation:** Both forms are derived with null verbal morphemes. (Piñón 2001, Alexiadou et al 2006)

- **Anticausativization:** A null verbal morpheme or reflexive pronoun derives the inchoative variant. (suggested by lexical semantic analysis of Levin and Rappaport-Hovav 1995)

- **Causativization:**
  - **Morphological:** A null verbal morpheme derives the causative variant. (Pesetsky 1995, Harley 1995, Pylkkänen 2002)
  - **Semantic Shift:** The meaning is due to a purely semantic, non-morphological causative shift in the causative variant. (Bittner 1999)
Behavioral Predictions

- Previous work has found processing costs due to lexical semantic complexity (McKoon and Macfarland 2002, Gennari and Poeppel 2003).

<table>
<thead>
<tr>
<th>Theory</th>
<th>Processing Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate Derivation</td>
<td>Inch = Caus</td>
</tr>
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<td>Anticausativization</td>
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</tr>
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<td>Causativization via Morphology</td>
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- Our Hypothesis: English zero-derived causative-inchoative verbs involve causativization.
Materials
## Stimuli Design

<table>
<thead>
<tr>
<th>Sentence</th>
<th>Group</th>
<th>Transitivity</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>What did the explosion <strong>sink</strong> near the harbor?</td>
<td>Causative-Inchoative</td>
<td>Transitive</td>
<td>Caus</td>
</tr>
<tr>
<td>When did the boat <strong>sink</strong> near the harbor?</td>
<td>Causative-Inchoative</td>
<td>Intransitive</td>
<td>Inch</td>
</tr>
<tr>
<td>What did the professor <strong>read</strong> for the seminar?</td>
<td>Activity</td>
<td>Transitive</td>
<td>TransAct</td>
</tr>
<tr>
<td>When did the professor <strong>read</strong> for the seminar?</td>
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- Activity verbs serve as a control for number of arguments.
- Question format indicates transitivity prior to verb presentation.
- If there is a cost for the ambiguity of transitivity in “when” questions, it should go against our hypothesis (intransitive variants are more ambiguous).
- If there is a cost for additional A-movement in inchoatives (as unaccusatives), this also should also work against our hypothesis.
- 37 quadruplets, 110 fillers
Graphical representation of behavioral predictions

- At or following the verb:

  - Separate Derivation
  - Anticausativization
  - Causativization
Experiment 1:
Self-paced reading time
Experiment 1: Data Collection & Analysis

Data Collection
- 32 Subjects
- Self-paced moving window (word-by-word)
- Task: End of sentence sensicality judgments

Data Preprocessing
- Removed all trials judged nonsensical (13%)
- Removed:
  1 outlier subject (Acc. < 70%)
  4 outlier items (Acc. < 60%)
- Removed as outliers all RTs > 2000ms or < 200ms

Statistical Analysis
- Hierarchical regression (Gelman & Hill 2006; Baayen et al. 2008) treating Subjects and Items as random effects
- Including control predictors for Word length, Frequency, Pre-verb reading times, Sentence Acceptability, Trial Order
- Further tested the effect of transitivity independent of acceptability using step-wise regression
Experiment 1: Results

**Causative Activity**
- sink
- read

**RT, Verb**
- Trans
- Intrans

**RT, Verb+1**
- *Interaction, β = .14, t = 4.20*
- Pairwise: Stepwise effect for transitivity in causative verbs,
  \( \chi^2(1) = 6.43, p = .01 \)

**RT, Verb+2**
- the...
- the...
Experiment 1: Results

RT, Verb + 1

Reading Time (msec)

Activity  Causative

Causativization
Experiment 1: Discussion

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- Causativization hypotheses supported
- Is the cost morphological, or purely semantic?
Experiment 2: Magnetoencephalography
Morphology and Semantics in MEG

- Magnetoencephalography (MEG): technique for observing cortical brain activity with a high sensitivity to both spatial and temporal characteristics.
- MEG has been used to identify the neural correlates of various linguistic computations and representations.
- Profile of lexical (morpheme) access:
  - M350: left temporal cortex ~300-450ms
    (Embick et al 2001, Pylkkänen, Stringfellow, & Marantz 2002)
- Profile of semantic composition/coercion:
  - AMF: Anterior midline field ~400-500ms
    (Pylkkänen & McElree 2007, Brennan & Pylkkänen 2008)
MEG Predictions

- Additional activity predicted for causatives in:

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<th>AMF 400-500ms</th>
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<tr>
<td>Morphological Causativization</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Semantic Shift</td>
<td></td>
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Experiment 2: Data Collection & Pre-processing

Collection Notes
- 16 subjects
- Same stimuli as experiment 1, presented word-by-word, 300ms per word, 300ms between words
- Task: End of sentence sensicality judgments
- 157 axial gradiometer, KIT/NYU Machine
- Recorded at 1000hz 200hz low-pass filter
- Resampled to 250hz low-pass filter at 40hz

Data Preprocessing
- Removed trials > 2000ft
- Removed “no” trials
- Subject outlier: 1 subject, acc < 70% (final N = 15)
Experiment 2: Data Analysis

**Source Analysis**
- Sensor data averaged per condition within subjects
- Distributed source analysis, with a minimum $l_2$ norm solution
  - Source-estimation using MNE software (Martinos center, MGH)
  - Sources cortically constrained using average MNI cortex
  - Source Solution: ~2600 sources per hemisphere, normal to cortical surface
- Noise normalized $dSPM$, SNR=2

**Statistics**
- Pairwise comparison, millisecond-by-millisecond, using hierarchical regression
- Multiple comparison correction using a cluster-based permutation test (Maris & Oostenveld 2006)
Experiment 2: Regions of Interest

13 fronto-temporal left-hemisphere regions of interest
ROIs defined based on anatomical atlas (Desikan-Killiany atlas: Desikan et al. 2006)
Experiment 2: Significant ROIs

- pars opercularis
- medial orbitofrontal
- posterior middle temporal
Experiment 2: Results

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<th>Post middle temporal</th>
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- **Medial orbitofrontal**
  - Graph showing activity over time with a peak at around 500 msec.
  - Significance level: $p < .1$

- **Post middle temporal**
  - Graph showing activity over time with a peak at around 500 msec.
  - Significance level: $p < .05$

- **Pars opercularis**
  - Graph showing activity over time with a peak at around 500 msec.
  - Significance level: $p < .05$

**Legend:**
- Solid line: Transitive (Causative)
- Dashed line: Intransitive (Inchoative)
Experiment 2: Discussion

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- Data point toward a morphological analysis.
- Further work is necessary to establish the specific role of observed activity.
Conclusions

- The behavioral profile of zero-derived causatives in English suggests a causativization analysis in processing.
- MEG data support this conclusion and effects observed suggest that both semantic composition and lexical access costs are implicated in causative processing.
- These initial results suggest that psycholinguistic and neurolinguistic data of this kind may be able to shed new light on questions of lexical semantic representation.


• Harley, H. 1995. Subject, events, and licensing. Doctoral Dissertation, MIT.


