Negative polarity illusions and the format of hierarchical encodings in memory

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Abstract
Linguistic illusions have provided valuable insights into how speakers mentally encode and navigate complex structured representations during real-time language comprehension. A parade case involves illusory licensing of negative polarity items (NPIs) like *ever*, where comprehenders temporarily accept sentences with an illicit NPI in on-line measures, but later judge those same sentences as unacceptable after more reflection in off-line tasks. Existing accounts of the illusion differ in their views of how NPI licensing obtains, but agree that the illusion reflects a noisy on-line implementation of the licensing mechanism. In contrast, we show across seven experiments (off-line and on-line measures and computational modeling) that the position of the NPI strongly modulates the illusion, which implies that the illusion cannot simply be due to a noisy licensing mechanism. Rather, we suggest that this effect reflects changes over time in how hierarchical representations are encoded in memory. Contrary to the widespread assumption that the format of hierarchical representations remains constant as a parse is extended, we argue that sentence encodings change from a transparent format that is highly susceptible to retrieval interference to a more opaque format that strongly resists interference. This shift in the representational format prevents illusory licensing errors, and hence yields greater processing accuracy. These findings lead to a new conception of how linguistic illusions do and do not arise, in which variable susceptibility to illusions is a consequence of the representational format of hierarchical encodings in memory. In discussion, we relate the current findings to parallel findings from research on feature binding in visual cognition.

Keywords
sentence processing, negative polarity, linguistic illusions, memory, binding, representation
1. Introduction

Successful language comprehension requires the ability to efficiently encode and navigate complex linguistic representations on a rapid time-scale. This ability is demonstrated perhaps most clearly in cases where the parser must establish linguistic relations between temporally distant words, phrases, and sentences. These non-adjacent relations can span a potentially large amount of material, creating long-distance dependencies that rely on working memory to rapidly recover the necessary information from the preceding context. For example, upon encountering the verb *purchased* in (1), a representation of the noun phrase (NP) *the painting* must be retrieved from memory to integrate it as the underlying object of the verb.

(1) It was the painting by Van Gogh that the curator from the museum recently purchased.

In order to account for the wide range of linguistic dependencies that are frequently encountered in natural language, theories of working memory and language comprehension must explicitly characterize: (i) encoding operations: how hierarchical linguistic representations are encoded in memory in a format that makes previously processed information readily accessible for ongoing parsing operations, and (ii) access operations: how this information is accessed and extracted from the encodings.

Recent research aimed at describing these operations has used linguistic illusions as a valuable tool to examine how the parser encodes and accesses complex structured representations during real-time comprehension (Ferreira, 2003; Ferreira & Patson, 2007; Phillips, Wagers, & Lau, 2011; Townsend & Bever, 2001). Linguistic illusions are cases where comprehenders temporarily process ungrammatical sentences as if they were acceptable in speeded tasks or in on-line measures such as reading times or event-related potentials (ERPs), but later judge those same sentences as unacceptable in untimed, off-line tasks. They are typically observed as eased processing of ungrammatical dependent elements in on-line measures, due to the presence of a semantically compatible licensor that is in a structurally illicit position. This eased processing has been argued to reflect a memory access error that makes ungrammatical sentences temporarily appear to be well-formed, and it has been presented as evidence that comprehenders consider ungrammatical candidates during on-line dependency formation (Vasishth, Brüssow, Lewis, & Drenhaus, 2008; Wagers, Lau, & Phillips, 2009).
1.1 Illusory negative polarity item licensing

One linguistic illusion that has received much attention in recent research on memory and language processing involves illusory licensing of negative polarity items (NPIs). NPIs are words like ever, any, yet, or phrases like lift a finger or a damn thing that are licensed in the scope of a downward entailing (DE) expression (Ladusaw, 1979). DE expressions license logical inferences from superset to subset within their scope, i.e., they entail a more specific proposition. For example, the statement Jack didn’t eat an apple entails that Jack didn’t eat a red apple, whereas Jack ate an apple does not entail that Jack ate a red apple. Negative-like elements such as no, not, few, rarely, and doubt, as well as conditionals and expressions of surprise are DE expressions that can license NPIs (Giannakidou, 2011; Von Fintel, 1999). Current accounts of negative polarity phenomena claim that the licensing conditions on NPIs reflect an interaction between the semantic features of NPIs and the semantic and pragmatic properties of the environments that host NPIs (Chierchia, 2006; Giannakidou, 2011; Horn, 2010; Israel, 2004; Kadmon & Landman, 1993; Krifka, 1995; Ladusaw, 1979; Linebarger, 1987). Under these accounts, the scope requirement on NPI licensing can be viewed as an emergent property, rather than an explicit grammatical constraint. Nonetheless, for current purposes, a NPI must appear in the scope of a DE expression in order to obtain the necessary semantic and pragmatic effect. For example, the NPI ever in (2a) is appropriately licensed because it appears in the scope of a negatively quantified NP. The scope of negation for purposes of NPI licensing corresponds roughly to the c-command domain of negation, i.e., the structural sister of negation and any element contained within the structural sister.\(^1\) When negation is absent (2b), or fails to scope over the NPI (2c), the NPI is not licensed.

\[
(2) \quad \begin{align*}
\text{a. No diplomats} & \text{ have ever supported a drone strike.} \\
\text{b. *The diplomats have ever supported a drone strike.} \\
\text{c. *The diplomats that no congressmen could trust have ever supported a drone strike.}
\end{align*}
\]

\(^1\) However, there are cases that call for elaboration of the c-command generalization. For example, in the sentence Nobody’s mother has ever served ice cream for dinner, the NPI ever can be licensed even though it is not syntactically c-commanded by the negation. In this case, it appears that the entire NP nobody’s mother counts as the relevant c-commander.
Sentences like those in (2b) and (2c) are reliably judged to be unacceptable in off-line tasks, where participants are given sufficient time to make their judgment. However, in time-sensitive measures, sentences like (2c) are frequently processed as if they were acceptable, leading to illusory licensing effects. For example, Drenhaus, Saddy, and Frisch (2005) used speeded-acceptability and ERP measures to test native German speakers’ sensitivity to the licensing conditions of the German NPI *jemals* (‘ever’) in sentences like (3).

(3)  

a. *Kein Mann, der einen Bart hatte, war *jemals* glücklich.* (grammatical licensor)  
   ‘No man who had a beard was ever happy.’

b. *Ein Mann, der *keinen Bart* hatte, war *jemals* glücklich.* (intrusive licensor)  
   ‘A man who had no beard was ever happy.’

c. *Ein Mann, der einen Bart hatte, war *jemals* glücklich.* (no licensor)  
   ‘A man who had a beard was ever happy.’

The NPI is appropriately licensed in (3a) because it appears in the scope of the negatively quantified NP *Kein Mann* (‘no man’). Both (3b) and (3c) are ungrammatical: the licensor in (3b) does not scope over the NPI, and (3c) has no licensor. Results of a speeded-acceptability task showed that the presence of an intrusive licensor in ungrammatical sentences like (3b) increased rates of acceptance relative to ungrammatical sentences like (3c) that did not have a licensor at all. ERP measures showed that while both ungrammatical sentences elicited an N400 effect upon processing an illicit NPI, the amplitude of the N400 for sentences with an intrusive licensor was significantly reduced relative to the no licensor condition. These findings have been corroborated in German and English using eye-tracking (Vasishth et al., 2008), speeded-acceptability, self-paced reading (Xiang, Dillon, & Phillips, 2006), and ERPs (Xiang, Dillon, & Phillips, 2009).

The key finding from these studies is that the disruption associated with processing an illicit NPI was significantly reduced in sentences that contain a semantically compatible intrusive licensor that is in a structurally illicit or non-commanding position. This effect suggests that in some portion of trials, comprehenders treated the illicit NPI as if it were acceptable, or on a par with the grammatically licensed cases. That is, the presence of an intrusive licensor can ease the processing of an illicit NPI online, making an ungrammatical sentence temporarily appear well-formed. It is important to note that the illusory licensing effect seen for sentences like (2c) and
(3b) is not a case of variable or incorrectly described grammar or of a negative quantifier taking scope outside of its clause. Comprehenders agree on the unacceptability of these sentences when they are given sufficient time. It is the mismatch between the behavior obtained by sampling immediately after the appearance of the NPI in on-line measures and the behavior obtained by sampling at a later point in off-line measures that makes this effect count as a linguistic illusion.

Vasishth and colleagues have presented illusory licensing effects as evidence for a general dependency formation mechanism that is sensitive to partial matches between retrieval cues and memory encodings (Vasishth et al., 2008). Their account is based on recent findings of similarity-based interference effects in on-line dependency resolution, which suggest that at least some encodings of linguistic structure in memory allow matches to their sub-parts (e.g., Gordon, Hendrick, & Johnson, 2001, 2004; Gordon, Hendrick, Johnson, & Lee, 2006; Gordon, Hendrick, & Levine, 2002; R. L. Lewis, 1996; Van Dyke & Lewis, 2003; Van Dyke & McElree, 2006). According to Vasishth and colleagues, encountering an NPI initiates a retrieval for an item in memory that has the properties [+negative] and [+c-command]. Illusory licensing effects can arise when a non-commanding licensor is erroneously retrieved due to a partial match to [+negation], leading to facilitated processing of an otherwise unlicensed NPI. An alternative account proposed by Xiang and colleagues argues that the illusion reflects over-active pragmatic accommodation, rather than mis-retrieval (Xiang et al., 2009). Their account is based on the observation that in addition to direct licensing through negation, NPIs may also be licensed through negative implicatures. For instance, the NPI ever is licensed in a sentence like (4a) through a negative implicature (4b).

(4) a. I am surprised that John ever finished that assignment.
   b. I expected that John would not finish that assignment.

According to Xiang and colleagues, the parser may over-apply the pragmatic licensing conditions on NPIs in sentences like (3b), where an interaction between embedded negation and the semantics of relative clauses could generate an unwarranted pragmatic implicature that may spuriously licensing the illicit NPI.

The accounts of illusory NPI licensing proposed by Vasishth et al. (2008) and Xiang et al. (2009) differ in their views about the licensing conditions on NPIs, but agree that NPI licensing
is a function of (i) the licensing conditions on NPIs, (ii) the encoding of the context, and (iii) noisy access mechanisms. Under both accounts, the illusion may be understood as a kind of partial-match effect, and suggests that the licensing mechanism can access semantic licensing features on-line, independently from the position of those features in the structured representation of the sentence. Importantly, these studies have tested for illusory licensing effects by sampling at different time points after the appearance of the NPI, and they have shown that sensitivity to the structural properties of a potential licensor grows as the lag from the NPI to the sampling point increases.

The mismatch between sampling immediately after the appearance of the NPI in on-line measures and sampling at a later point in off-line measures remains poorly understood. However, the mismatch could reflect an improvement over time in the signal-to-noise ratio: by holding all components of the NPI licensing mechanism (i.e., the licensing conditions, the encoding of the context, and the access mechanisms) constant, while assuming that the cognitive architecture is noisy, the signal-to-noise ratio can improve over time with repeated access attempts. For example, an outcome of intrusive licensing that has a 25% probability of occurrence on a single access trial will have a substantially reduced probability of being the dominant outcome over the course of multiple access trials, leading to greater grammatical accuracy (see S. Lewis & Phillips, submitted, for discussion).

1.2 The present study

Existing research on NPI illusions has highlighted the impact of the interval after the appearance of the NPI, and the resulting theories such as those proposed by Vasishth et al. (2008) and Xiang et al. (2009) have emphasized that the sensitivity of the access mechanisms to the structural properties of a potential licensor varies as a function of the amount of time that a comprehender has had to process the NPI, with more time yielding greater grammatical accuracy. These theories predict variation in the time or position where the NPI appears in the sentence should have no impact on the illusory licensing effect, given the assumption that the components of the licensing mechanism (i.e., the licensing conditions, the encoding of the context, and the access mechanisms) are stable over time.

In the present study we focus on a different part of the time course of NPI licensing, namely the time that elapses between the context containing the potential licensors and the
introduction of the NPI. Converging evidence from seven studies using acceptability ratings, speeded-acceptability judgments, self-paced reading, and computational simulations show that susceptibility to illusory licensing is strongly impacted by the position of the NPI relative to the intrusive licensor. Specifically, the sensitivity of the access mechanisms to the structural properties of a potential licensor grows as the distance from the intrusive licensor increases, leading to a disappearance of the illusory licensing effect. These results are not predicted by existing accounts and they imply that the illusion cannot simply be due to a noisy on-line access mechanism. Rather, we suggest that the selective nature of the illusion reflects changes over time in how hierarchical representations are encoded in memory. We argue that whereas the licensing conditions and access mechanisms remain constant as a parse is extended, the representation of the sentence in memory changes over time from a format where individual semantic and structural licensing features can be readily accessed for partial-matching to one where semantic licensing features are no longer accessible independently from the position of those features in the structured sentence representation, preventing further partial-match illusory licensing effects. We present these findings as evidence for rapid changes in the representational format of sentences in memory during real-time language comprehension. Lastly, we briefly discuss the computational properties of representational change, and we relate the current findings to parallel findings from research on feature binding in visual cognition (Chun & Potter, 2000; Holcombe & Clifford, 2012; Treisman & Gelade, 1980; Treisman & Schmidt, 1982; Treisman, Sykes, & Gelade, 1977; Wolfe, 2007, 2012).

The contribution of this study is threefold. First, we present a new set of findings on where linguistic illusions do and do not arise. Second, we integrate experimental and computational evidence to argue that the encoding of structure is not fixed over time and that variable susceptibility to linguistic illusions is a consequence of the representational format of hierarchical encodings in memory. Third, we highlight potentially important parallels between binding processes in language comprehension and visual cognition.

2. Direct comparison of ‘ever’ and ‘any’

NPI illusions have provided valuable insights into how linguistic representations are encoded and navigated mentally. However, rather general conclusions about the encoding and
access mechanisms have been drawn from a narrow range of findings. For example, while existing evidence shows that illusory licensing is robust across multiple tasks and languages, all previous demonstrations of illusory NPI licensing involve the NPI *ever* and a configuration where the intrusive licensor is the subject or object of a subject-modifying relative clause (e.g., (2c) and (3c)). Existing accounts such as those proposed by Vasishth et al. (2008) and Xiang et al. (2009) predict that all other NPIs should behave similarly with respect to illusory licensing. In the first set of experiments, we directly compared the NPIs *ever* and *any*. The prototypical NPI *any* is similar to the NPI *ever*, in that it may be directly licensed in DE contexts, as shown in (5).

(5)  
   a. Nobody has eaten any of the cake that Mary made.  
   b. No student wants any homework over the holiday.

The NPI *any* has not featured prominently in previous research on the processing of NPIs due to the confound of the so-called *free-choice* interpretation. Free-choice *any* is licensed in non-DE contexts that invite a choice among a set of alternatives. However, unlike its NPI counterpart *ever*, free-choice *any* is not polarity sensitive and it is acceptable without negation as shown in (6) (see Giannakidou, 2001, for discussion). Consequentially, *any* is less amenable to tests of illusory NPI licensing that rely on a negative intrusive licensor.

(6)  
   a. Sally will marry any doctor.  
   b. Pick a card, any card.  
   c. Students can purchase any book online.

It may be possible, however, to force polarity sensitivity for *any* in contexts that do not provide the kind of alternatives needed for the free-choice interpretation. For example, the lack of a clear set of alternatives for the abstract mass noun *satisfaction* in (7a) renders the free-choice interpretation of *any* infelicitous. The negative polarity interpretation, by contrast, is readily accessible when *any* appears in the scope of negation, as in (7b). If comprehenders reliably interpret *any* as a negative polarity item in contexts like (7b), then it may provide a new context to test the scope of illusory NPI licensing.

(7)  
   a. Sally will marry any doctor.  
   b. Pick a card, any card.  
   c. Students can purchase any book online.
(7)  a. The criminals felt any satisfaction from the crime.
    b. No criminals felt any satisfaction from the crime.

Although semantic analyses of NPIs (e.g., Chierchia, 2006; Giannakidou, 2011; Kadmon & Landman, 1993) treat *any* and *ever* similarly in licensing environments like (7a), these two items could nevertheless show different profiles in on-line comprehension. For instance, *any* and *ever* must appear in different positions of the sentence due to differences in syntactic category (e.g., *any* is a determiner whereas *ever* is an adverb). This unavoidable difference consequently varies the distance from the licensor, and it is possible that well-known effects of distance, such as decay (e.g., Gibson, 2000) or (anti-)locality effects (e.g., Konieczny, 2000), could lead to more or fewer errors of illusory licensing for *any* compared to *ever*.

2.1 Experiment 1: Off-line comparison of ‘ever’ and ‘any’

In Experiment 1, we compared sentences with the items *ever* and *any* using untimed, off-line acceptability ratings. The goal of this experiment was to determine whether comprehenders would reliably interpret *any* as a negative polarity item, rather than a free-choice item, when it occurred with an abstract mass term that does not support the kind of alternatives needed for the free-choice interpretation. If comprehenders interpret *any* as a negative polarity item, then we should expect to see rejection of sentences that lack a licensor. By contrast, if comprehenders interpret *any* as a free-choice item, then we should expect to see either no difference between sentences with *any*, or at least increased acceptability for sentences with an intrusive licensor and no licensor relative to their *ever* counterparts. Sentences with the NPI *ever* provided baseline conditions against which comprehenders’ sensitivity to the negative polarity interpretation was measured.

2.1.1 Participants

Participants were 24 native speakers of English who were recruited using Amazon’s Mechanical Turk crowdsourcing web-service (https://aws.amazon.com/mturk). All participants in this and the following experiments provided informed consent, and they were required to pass a short English proficiency test in order to participate in the experiment for payment. Participants in Experiment 1 were compensated $2.50. The experiment lasted approximately 15 minutes.
2.1.2 Materials

Experimental materials consisted of 36 sets of 6 items, which varied in terms of the presence and structural location of an NPI licensor (grammatical licensor / intrusive licensor / no licensor), and the type of NPI (*ever* / *any*). All items contained a subject NP that was modified by an object relative clause. This subject NP was always followed by a main clause predicate that contained the NPI. The grammatical licensor condition had the NPI licensor *no* as the determiner of the main clause subject NP. The intrusive licensor condition had the same licensor as the determiner of the relative clause subject NP. In the no licensor condition, the NPI licensor was replaced with the definite determiner *the*, which fails to license NPIs. The relative clause was always followed by the auxiliary *have*, which served to clearly mark the right edge of the relative clause. This demarcation was included to ensure that participants would correctly construct a parse in which the intrusive licensor did not c-command the NPI. The NPI *ever* always appeared immediately following the auxiliary. The NPI *any* was always interpolated between the main clause verb to its left and an abstract mass noun to its right. An example set of items is given in Table 1, showing all 6 conditions.

<table>
<thead>
<tr>
<th></th>
<th>Grammatical Licensor</th>
<th>Intrusive Licensor</th>
<th>No Licensor</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>ever</em></td>
<td>No authors [that the critics recommended] have <em>ever</em> received acknowledgment for a best-selling novel.</td>
<td>The authors [that <em>no</em> critics recommended] have <em>ever</em> received acknowledgment for a best-selling novel.</td>
<td>The authors [that the critics recommended] have <em>ever</em> received acknowledgment for a best-selling novel.</td>
</tr>
<tr>
<td><em>any</em></td>
<td>No authors [that the critics recommended] have received <em>any</em> acknowledgment for a best-selling novel.</td>
<td>The authors [that <em>no</em> critics recommended] have received <em>any</em> acknowledgment for a best-selling novel.</td>
<td>The authors [that the critics recommended] have received <em>any</em> acknowledgment for a best-selling novel.</td>
</tr>
</tbody>
</table>

Table 1: Sample set of items for Experiment 1. NPIs and NPI licensors are in bold.
Each participant rated 108 sentences, consisting of 36 NPI sentences and 72 filler sentences. The 36 sets of NPI items were distributed across 6 lists in a Latin Square design. The filler sentences were of similar length and complexity to the NPI sentences, but lacked an NPI. Roughly half of the filler sentences used determiners similar to those used in the NPI sentences in similar positions to prevent the possibility that participants might develop superficial reading strategies based on the distribution of the determiners in the NPI sentences. Materials were balanced so that across the experiment half of the sentences were ungrammatical. The anomalies in the filler sentences comprised a variety of grammatical violations, including agreement errors, pronoun gender violations, and unlicensed verbal morphology. Materials for this and all other experiments in this article can be found at http://ling.umd.edu/~dparker3/.

2.1.3 Procedure

Sentences were presented using the web-based Ibex presentation software (Alex Drummond, http://spellout.net/ibexfarm/). Participants were instructed to rate the acceptability of each sentence using a 7-point scale, with ‘7’ being the most acceptable, and ‘1’ the least acceptable. Participants could take as much time as needed to rate each sentence, so long as they finished the experiment within the 30 minute time restriction imposed by the Mechanical Turk session. Each sentence was displayed in its entirety on the screen along with the rating scale. Participants could click boxes to enter their rating, or use a numerical keypad. The order of presentation was randomized for each participant. Eight practice items were presented before the beginning of the experiment.

2.1.4 Data analysis

Data were analyzed using linear mixed-effects models, with fixed factors for experimental manipulations and random effects for participant and item. We estimated models using the lme4 package (Bates, Maechler, & Bolker, 2011) in the R software environment (R Development Core Team, 2011) . We used sum contrasts for experimental fixed effects (grammaticality and intrusion), and a fully-specified random effects structure, which included random intercepts and slopes for all fixed effects by participants and by items (Baayen, Davidson, & Bates, 2008; Barr, Levy, Scheepers, & Tily, 2013). For all statistical analyses reported in this
paper, a fixed effect was considered significant if the absolute \( t/z \)-value was greater than 2 (Gelman & Hill, 2007).

2.1.5 Results

The results of the off-line acceptability judgment study are presented in Table 2. A significant main effect of grammaticality was observed for both NPIs, as ratings were substantially higher for sentences with a grammatical licensor as compared to sentences with an intrusive licensor and no licensor (\( \text{ever}: \beta=2.6, SE=0.34, t=7.72; \text{any}: \beta=2.6, SE=0.34, t=7.79 \)). No significant differences were observed between the ungrammatical conditions for either NPI.

<table>
<thead>
<tr>
<th></th>
<th>GRAMMATICAL LICENSOR</th>
<th>INTRUSIVE LICENSOR</th>
<th>NO LICENSOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>ever</td>
<td>4.68 (±0.20)</td>
<td>2.02 (±0.13)</td>
<td>1.93 (±0.13)</td>
</tr>
<tr>
<td>any</td>
<td>4.46 (±0.19)</td>
<td>1.83 (±0.11)</td>
<td>1.74 (±0.10)</td>
</tr>
</tbody>
</table>

Table 2: Mean acceptability ratings and standard errors by participants for Experiment 1. Values are on a 7-point scale, with ‘7’ being the most acceptable, and ‘1’ the least acceptable.

2.1.6 Discussion

Untimed acceptability ratings from Experiment 1 showed nearly identical profiles for \textit{any} and \textit{ever}, which suggests that participants interpreted \textit{any} as negative polarity item, rather than a free-choice item. Sensitivity to the free-choice interpretation of \textit{any} would predict either no differences between the sentences with \textit{any}, or at least increased acceptability for sentences with an intrusive licensor and no licensor relative to their \textit{ever} counterparts. This was not the case, however, as the magnitude of the grammaticality effect did not reliably differ across NPIs. For both sets of items, participants showed robust sensitivity to the structural licensing conditions on negative polarity items, as they reliably rated sentences with a grammatical NPI licensor higher than sentences with an intrusive licensor and no licensor. Furthermore, there was no evidence that the presence of a semantically compatible, but structurally illicit intrusive licensor improved the off-line acceptability of an illicit NPI. These results demonstrate that the free-choice
interpretation of _any_ can be blocked in favor of the negative polarity interpretation in certain contexts, and more generally, they provide a baseline demonstration of the absence of illusory licensing effects in untimed, off-line tasks.

2.2 _Experiment 2: Speeded-acceptability comparison of ‘ever’ and ‘any’_

Experiment 2 used speeded-acceptability judgments to directly compare the NPIs _ever_ and _any_. The main aim of this experiment was to test whether the illusory licensing effect that is commonly observed for the NPI _ever_ would extend to the NPI _any_. Previous studies on the processing of NPIs have shown that comprehenders are most susceptible to illusory NPI licensing in on-line, time sensitive measures. The speeded-acceptability judgment task used in Experiment 2 provides a simple measure of on-line processing decisions, and has been shown to reliably elicit the illusory NPI licensing effect by restricting the amount of time that comprehenders have to reflect on grammatical intuitions (e.g., Drenhaus et al., 2005; Xiang et al., 2006).

2.2.1 _Participants_

Participants were 18 native speakers of English from the University of Maryland community. Participants were either compensated $10 or received credit in an introductory linguistics course. All participants were naïve to the purpose of the experiment. The speeded-acceptability task lasted approximately 20 minutes, and was administered as a part of a one-hour session involving unrelated experiments.

2.2.2 _Materials_

Experiment materials consisted of the same 36 sets of 6 items as in Experiment 1, with the same filler sentences.

2.2.3 _Procedure_

Sentences were presented on a desktop PC using the Ibex presentation software. Sentences were presented one word at a time in the center of the screen in a rapid serial visual presentation (RSVP) paradigm (Potter, 1988) at a rate of 300 milliseconds per word. A response screen appeared for 3 seconds at the end of each sentence during which participants made a
‘yes/no’ response by button press. Participants were instructed to read each sentence carefully, and to judge each sentence according to its acceptability in colloquial speech. If participants waited longer than 3 seconds to respond, they were given feedback that their response was too slow. The order of presentation was randomized for each participant. Eight practice items were presented before the beginning of the experiment.

2.2.4 Data analysis

Data were analyzed using logistic mixed-effects models, since the dependent measure was categorical (i.e., ‘yes’ or ‘no’). We used sum contrasts for experimental fixed effects (grammaticality and intrusion), and a fully-specified random effects structure, which included random intercepts and slopes for all fixed effects by participants and by items (Baayen et al., 2008; Barr et al., 2013).

2.2.5 Results

Figure 1 shows the proportion of ‘yes’ responses for the 6 experimental conditions in Experiment 2. Results showed reliable detection of an unlicensed NPI, as grammatical sentences were more likely to be accepted than their ungrammatical counterparts (ever: $\beta=2.1$, SE=0.33, $z=6.44$; any: $\beta=2.4$, SE=0.41, $z=5.76$). But results for the ungrammatical conditions sharply diverged. Contrasting illusory licensing profiles were observed for ever and any, as reflected by an interaction between intrusion and NPI type ($\beta=1.16$, SE=0.49, $z=2.37$). Planned pairwise comparisons revealed that this interaction was driven by a significant illusory licensing effect for ever ($\beta=1.3$, SE=0.38, $z=-3.50$), as participants were more likely to accept ungrammatical sentences with an intrusive licensor than ungrammatical sentences with no licensor. No such effect was observed for any.
2.2.6 Discussion

In Experiment 2, we investigated the scope of the illusory NPI licensing effect in a direct comparison of the two NPIs *ever* and *any*. Speeded-acceptability judgments revealed contrasting illusory licensing profiles. The NPI *ever* showed a clear illusory licensing effect, as comprehenders were more likely to accept ungrammatical sentences with *ever* when an intrusive licensor was present. The profile observed for *ever* replicates previous findings of illusory NPI licensed noted in Drenhaus et al. (2005) and Xiang et al. (2006, 2009). The NPI *any*, by contrast, showed no such illusory licensing effect, as the presence of an intrusive licensor did not increase rates of acceptance of sentences that contained an illicit NPI.

However, one potential concern with the results of Experiment 2 is the high rate of acceptance of ungrammatical sentences with *any*. It is possible, for example, that an illusory licensing effect for sentences involving the NPI *any* was masked by the increased rate of acceptance of sentences with no licensor. One factor that may differentially impact judgments is the free-choice interpretation of *any*. Although the off-line judgments from Experiment 1
suggests that comprehenders ultimately favor the negative polarity interpretation of any in configurations such as those used in Experiment 2, the mechanisms that are recruited for incremental processing may have nevertheless accessed the free-choice interpretation before the restricting abstract mass noun was encountered in the input sequence. It is possible, then, that in some portion of trials, some residue of this temporary free-choice interpretation could have influenced end-of-sentence judgments in an attempt to make sense of an ungrammatical sentence. In Experiment 3, we investigate this possibility by examining the time course of the contrasting profiles observed for ever and any.

2.3 Experiment 3: Self-paced reading comparison of ‘ever’ and ‘any’

To investigate the time-course of the contrasting profiles observed for ever and any, we conducted a self-paced reading experiment using the same items from Experiments 1 and 2. In self-paced reading measures, illusory licensing effects are predicted at the NPI as facilitated reading times for ungrammatical sentences with an intrusive licensor, relative to ungrammatical sentences with no licensor. The absence of an illusion, by contrast, is predicted as only a main effect of grammaticality, with no divergence in reading times for the two types of ungrammatical sentences.

2.3.1 Participants

Participants were 24 native speakers of English from the University of Maryland community. Participants were either compensated $10 or received credit in an introductory Linguistics course. All participants were naïve to the purpose of the experiment. The self-paced reading task lasted approximately 35 minutes, and was administered as a part of a one-hour session involving unrelated experiments.

2.3.2 Materials

Experimental materials consisted of the same 36 sets of 6 items as in Experiments 1 and 2. 72 grammatical fillers were also included, such that each participant read a total of 108 sentences. The filler sentences were of similar length and complexity to the NPI sentences, but lacked an NPI. Roughly half of the filler sentences used determiners similar to those in the NPI conditions in similar positions to prevent the possibility that participants might develop superficial reading
strategies based on the distribution of the determiners in the NPI sentences. Each sentence was followed by a comprehension question. Comprehension questions addressed various parts of the sentence to prevent the possibility that participants might develop superficial reading strategies whereby they extracted only the information necessary to answer the comprehension question without fully interpreting the sentence.

2.3.3 Procedure

Sentences were presented on a desktop PC in a moving-window self-paced reading display using the Linger software package (Doug Rohde, MIT). Sentences were initially masked by dashes, with white spaces and punctuation intact. Participants pushed the space bar to reveal each word. Presentation was non-cumulative, such that the previous word was replaced with a dash when the next word appeared on the screen. Each sentence was followed by a ‘yes/no’ comprehension question. Comprehension questions addressed various parts of the sentence in order to prevent participants from developing superficial reading strategies. For ungrammatical sentences, comprehension questions addressed only content prior to the NPI. Onscreen feedback was provided for incorrect answers. Participants were told to read more carefully if they answered multiple questions incorrectly. The order of presentation was randomized for each participant. Eight practice items were presented before the beginning of the experiment.

2.3.4 Data analysis

Self-paced reading times for experimental sentences were examined region-by-region. The regions used for analysis consisted of single words. Data were systematically treated against outliers. Reading times that exceeded 2000 ms. and 2.5 standard deviations by region and condition were excluded. One participant was excluded from analysis due to accuracy below 80%. Comprehension accuracy data were analyzed using logistic mixed-effects models, and reading times were analyzed using linear mixed-effects models. We used sum contrasts for experimental fixed effects (grammaticality and intrusion), and a fully-specified random effects structure, which included random intercepts and slopes for all fixed effects by participants and by items (Baayen et al., 2008; Barr et al., 2013).
2.3.5 Comprehension question accuracy

The mean comprehension question accuracy was 94%. The only reliable contrast was for the ungrammatical sentences with ever, which showed an 8.4% decrease in accuracy for sentences with an intrusive licensor (mean percentages: no licensor 97.9%, intrusive licensor 89.5%; \( \beta = -1.85, SE = 0.73, z = -2.53 \)).

2.3.6 Self-paced reading times

Figures 2 and 3 show the region-by-region condition means for sentences with the NPIs ever (Figure 2) and any (Figure 3).

Self-paced reading times: ever

Pre-critical regions (R1-7) – ever: The only significant effect found in the pre-critical regions was a main effect of grammaticality at region 3 (R3) immediately following NP1, as reflected by facilitated reading times for sentences with a grammatical licensor (\( \beta = -40.21, SE = 16.13, t = -2.49 \)). This effect was likely driven by a processing facilitation associated with negatively quantified NPs relative to definite NPs, however, this effect was short-lived and did not replicate in the sentences with any. No other significant effects for any of the experimental factors were observed in the pre-critical regions.

Critical NPI regions (R8-14) – ever: At the NPI ever (R8), there was a significant main effect of grammaticality, as reflected by a slowdown in ungrammatical conditions relative to the grammatical condition (\( \beta = -51.38, SE = 18.98, t = 2.70 \)). This grammaticality effect persisted into Regions 9-12 (R9: \( t = -2.75 \); R10: \( t = -3.67 \); R11: \( t = -2.82 \); R12: \( t = -2.82 \)). The critical NPI region also showed a significant illusory licensing effect, due to facilitated reading times for ungrammatical sentences with an intrusive licensor relative to ungrammatical sentences with no licensor (\( \beta = -63.41, SE = 26.84, t = -2.36 \)). The illusory licensing effect persisted into Region 9 (R9: \( t = -2.68 \)). No other significant effects for any of the experimental factors were observed in Regions 13-14.

Self-paced reading times: any

Pre-critical regions (R1-9) – any: No significant effects for any of the experimental factors were observed prior to the critical region.
Critical NPI regions (R10-14) – *any*: At the NPI *any* (R10), there was a significant main effect of grammaticality, as reflected by a slowdown in ungrammatical conditions relative to the grammatical condition ($\beta = -41.86$, SE=19.80, $t=2.11$). This effect persisted into Regions 11-12 (R11: $t=2.05$; R12: $t=2.34$). There was no reliable evidence for illusory licensing at the NPI region or the subsequent regions, as reading times in the ungrammatical conditions did not diverge. No other significant effects for any of the experimental factors were observed in Regions 13-14.

Direct comparison of *ever* and *any*: We directly compared the processing dynamics of *ever* and *any* using a linear mixed-effects model that included the factors of NPI type and illusory licensing and a fully-specified random effects structure. This analysis revealed contrasting illusory licensing profiles for *ever* and *any*, as reflected by a significant interaction between NPI type and illusory licensing ($\beta = -63.61$, SE=28.63, $t=2.22$).

![Graph showing reading time (ms) for each region with *ever*](image)

Figure 2: Experiment 3 self-paced reading results for sentences with the NPI *ever*. Region-by-region means separated by the presence and location of a potential licensor. Error bars indicate standard error of the mean. Sample sentence: *No*|*The*$_1$ *authors*$_2$ *that*$_3$ *the*|*no*$_4$ *critics*$_5$ *recommended*$_6$ *have*$_7$ *ever*$_8$ *received*$_9$ *acknowledgment*$_{10}$ *for*$_{11}$ *a*$_{12}$ *best-selling*$_{13}$ *novel*$_{14}$. 
Figure 3: Experiment 3 self-paced reading results for sentences with the NPI any. Region-by-region means separated by the presence and location of a potential licensor. Error bars indicate standard error of the mean. Sample sentence: No|The 1 authors 2 that 3 the|no 4 critics 5 recommended 6 have 7 received 8 any 9 acknowledgment 10 for 11 a 12 best-selling 13 novel 14.

2.3.6 Discussion

The most important finding from Experiment 3 is the replication of the contrasting illusory licensing profiles for ever and any that was observed in Experiment 2. This replication demonstrates that the contrast is robust across different measures. As in Experiment 2, the NPI ever showed a reliable illusory licensing effect, reflected in self-paced reading times as facilitated processing of an illicit NPI in the presence of an intrusive licensor. The NPI any, by contrast, showed no such illusory licensing effect, as the presence of an intrusive licensor did not ease the processing of an illicit NPI.

Importantly, sentences with any showed rapid detection of an illicit NPI, as reflected by equivalent slow-downs in both the intrusive licensor and no licensor conditions. This effect was observed immediately at the NPI region (R10), which demonstrates that structural negative polarity licensing conditions can have an immediate impact on on-line comprehension, at least in certain contexts. Immediate sensitivity to these structural conditions at any suggests that comprehenders initially pursued the negative polarity interpretation of this item, even before the restricting abstract mass noun was encountered in the input. This finding indicates that the absence of an illusory licensing effect for any in Experiment 2 cannot simply be due to the potential for a free-choice interpretation.

There are several possible explanations for the contrasting illusory licensing profiles observed for ever and any. One possibility is that the contrasting profiles reflect inherent
properties of the two NPIs. The NPIs *ever* and *any* differ along several dimensions, including syntactic category and quantificational status. For example, *any* is a quantificational determiner whereas *ever* is an adverb. Although current leading theories of polarity phenomenon treat *ever* and *any* similarly (e.g., Chierchia, 2006; Giannakidou, 2011), it is possible that these differences may have contributed to different profiles in on-line processing.

Another possibility is that the contrasting profiles reflect selective mis-identification or repair of *ever*, but not *any*. The NPI *ever* has a phonological and orthographic near neighbor, *never*. This near neighbor is semantically compatible with the sentence-initial context, and the parser could have accessed this near neighbor to generate a perfectly grammatical representation of an otherwise ungrammatical sentence. For instance, assuming a noisy-channel model of sentence comprehension (e.g., Gibson et al., 2013; Levy, 2008), comprehenders may have maintained some uncertainty about whether the input contained the NPI *ever*, or its near-neighbor *never*. It is possible, then, that in some portion of trials, comprehenders mis-identified *ever* as *never* in contexts that could not support a grammatical interpretation of the NPI. The NPI *any* was less likely to be mis-identified as one its near-neighbors, e.g., *many*, as this would result in semantic incompatibility with the abstract mass term, e.g., *many satisfaction*. However, we suggest that this account cannot capture the contrasting profiles for several reasons. First, this account does not predict that mis-identification should occur more in sentences with intrusive negation, which show more errors of illusory licensing relative to sentences that lack negation. Second, this account incorrectly predicts similar profiles for *ever* and *any*, and it incorrectly predicts immediate susceptibility to illusory licensing for *any*, since the restricting abstract mass term that would prevent re-analysis or phonological repair was not encountered until after the NPI. Self-paced reading times for *any*, however, showed resistance to illusory licensing immediately at the NPI.

A third possibility is that the contrasting profiles reflect differences between *ever* and *any* with respect to their linear position in the string and the parsing operations that precede these items. In the items that we tested, *ever* appeared pre-verbally, whereas *any* appeared post-verbally. Routine parsing operations associated with thematic binding at the main clause verb, for example, may have selectively reactivated the target main clause subject NP immediately prior to *any*, giving this NP an activation advantage that could reduce or eliminate intrusion from an intrusive licensor NP. No such activation bias would be available for *ever*, since it appeared
before the main clause verb. Alternatively, the linear difference could have given rise to a kind of anti-locality effect (Häussler & Bader, 2012; Konieczny, 2000). For example, the increased distance and additional intervening material between the NPI and the main subject NP for sentences involving *any* could have narrowed down the range of possible continuations or it could have changed some component of the NPI licensing process, such as the licensing conditions, the encoding of the context, or the access mechanisms, leading to a heightened sensitivity to an unlicensed NPI. No such anti-locality advantage would be available for *ever* because it appeared in an earlier position relative to *any*.

3. Direct comparison of pre- and post-verbal ‘ever’

The next set of experiments were designed to distinguish between accounts of the contrasting illusory licensing profiles for *ever* and *any* that appeal to lexical differences and selective repair on the one hand, and an account that appeals to positional differences on the other hand. We achieved this by holding the NPI constant, testing only *ever*, and by manipulating whether the NPI appeared pre-verbally or post-verbally. If the contrasting illusory licensing profiles observed in Experiments 2 and 3 reflect inherent differences between *ever* and *any* or selective repair of *ever*, then we expect to see similar illusory licensing effects across all positions. If, however, the contrasting profiles reflect positional differences between pre-verbal *ever* and post-verbal *any*, then we expect to see selective susceptibility to illusory licensing, with illusory licensing effects only in pre-verbal positions. We used both speeded-acceptability judgments (Experiment 4) and self-paced reading measures (Experiment 5) to directly compare the processing of *ever* in pre-verbal and post-verbal positions.

3.1 Experiment 4: Speeded-acceptability comparison of pre- and post-verbal *ever*

3.1.1 Participants

Participants were 18 native speakers of English from the University of Maryland. Participants were either compensated $10 or received credit in an introductory Linguistics course. All participants were naïve to the purpose of the experiment. The task lasted approximately 20 minutes, and was administered as a part of a one-hour session involving unrelated experiments.
3.1.2 Materials

Experimental materials consisted of 36 sets of 6 items, which varied in terms of the presence and structural location of an NPI licensor (grammatical licensor / intrusive licensor / no licensor), and the position of the NPI (pre-verbal / post-verbal). As in Experiments 2 and 3, the NPI licensor *no* appeared either as the determiner of the main subject (grammatical licensor) or as the determiner of the relative clause subject (intrusive licensor), or was replaced with the definite determiner *the* (no licensor). The relative clause was always followed by a three to four word prepositional phrase (PP), which served to clearly mark the right edge of the relative clause, ensuring that participants would correctly construct a parse in which the intrusive licensor did not c-command the NPI. The NPI *ever* appeared either immediately before the main clause verb (pre-verbal conditions), or immediately after the auxiliary of an embedded sentential complement clause (post-verbal conditions). An example set of items is given in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>GRAMMATICAL LICENSOR</th>
<th>INTRUSIVE LICENSOR</th>
<th>NO LICENSOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRE-VERBAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ever</td>
<td>No journalists [that the editors recommended for the assignment] <em>ever</em> thought that the readers would understand the complicated situation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The journalists [that <em>no</em> editors recommended for the assignment] <em>ever</em> thought that the readers would understand the complicated situation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The journalists [that the editors recommended for the assignment] <em>ever</em> thought that the readers would understand the complicated situation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>POST-VERBAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ever</td>
<td>No journalists [that the editors recommended for the assignment] thought that the readers would <em>ever</em> understand the complicated situation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The journalists [that <em>no</em> editors recommended for the assignment] thought that the readers would <em>ever</em> understand the complicated situation.</td>
<td></td>
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<tr>
<td></td>
<td>The journalists [that the editors recommended for the assignment] thought that the readers would <em>ever</em> understand the complicated situation.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Sample set of items for Experiment 4. NPIs and licensors are in bold.

3.1.3 Procedure

The same procedure was used as in Experiment 2.
3.1.4 Data analysis

Data analysis followed the same steps as in Experiment 2.

3.1.5 Results

Figure 4 shows the proportion of ‘yes’ judgments for the 6 experimental conditions of Experiment 4. Results showed reliable detection of an unlicensed NPI, as grammatical sentences were more likely to be accepted than their ungrammatical counterparts (pre-verbal ever: $\beta=2.8$, SE=0.51, $z=5.41$; post-verbal ever: $\beta=2.1$, SE=0.41, $z=5.26$). But judgments for the ungrammatical sentences sharply diverged. Contrasting illusory licensing profiles were observed for pre-verbal and post-verbal ever, as reflected in an interaction between illusory licensing and NPI position within the ungrammatical conditions ($\beta=1.01$, SE=0.49, $z=-2.04$). Planned pairwise comparisons revealed that this interaction was driven by a significant illusory licensing effect for pre-verbal ever ($\beta=1.2$, SE=0.39, $z=3.16$), as participants were more likely to accept ungrammatical sentences with an intrusive licensor than ungrammatical sentences with no licensor. No such effect was observed for post-verbal ever.

![Figure 4: Experiment 4 speeded-acceptability judgments. Mean percentage ‘yes’ responses for sentences with the NPI ever in a pre-verbal position (left) and a post-verbal position (right). Error bars indicate standard error of the mean.](image-url)
3.1.6 Discussion

Speeded-acceptability judgment results revealed the same modulation of illusions seen in the ever/any comparison, with contrasting illusory profiles for a single NPI ever in pre-verbal and post-verbal positions. Pre-verbal ever showed a reliable illusory licensing effect, as comprehenders were more likely to accept ungrammatical sentences when an intrusive licensor was present. This pattern replicates the illusory licensing effect observed for ever in Experiment 2, further demonstrating the robustness of the basic illusory licensing effect. Post-verbal ever, by contrast, showed no such illusory licensing effect, as the presence of an intrusive licensor did not reliably increase the rate of acceptance of sentences that contained an illicit post-verbal NPI.

The contrasting illusory licensing profiles observed for pre-verbal and post-verbal ever are consistent with the hypothesis that the contrasting illusory licensing profiles seen for the ever/any comparison reflect positional differences between the two NPIs. However, this requires further confirmation, and we return to a fuller discussion after Experiment 5.

3.2 Experiment 5: Self-paced reading comparison of pre- and post-verbal ‘ever’

Experiment 5 used self-paced reading to examine the time-course of the contrasting illusory licensing profiles for pre-verbal and post-verbal ever. As in Experiment 3, illusory licensing effects would manifest as a main effect of grammaticality, accompanied by facilitated readings for ungrammatical sentences with an intrusive licensor relative to ungrammatical sentences with no licensor. The absence of an illusion, by contrast, is predicted as only an effect of grammaticality, with no divergence in reading times for the ungrammatical sentences.

3.2.1 Participants

Participants were 24 native speakers of English from the University of Maryland. Participants were either compensated $10 or received credit in an introductory Linguistics course. All participants were naïve to the purpose of the experiment. The task lasted approximately 35 minutes, and was administered as a part of a one-hour session involving unrelated experiments.

3.2.2 Materials

Experimental materials consisted of the same 36 sets of 6 items as in Experiment 4. 72 grammatical fillers were also included, such that each participant read a total of 108 sentences.
The filler sentences were of similar length and complexity to the NPI sentences, but lacked an NPI. Roughly half of the filler sentences used determiners similar to those in the NPI conditions, in similar positions, to prevent the possibility that participants might develop superficial reading strategies based on the distribution of determiners in the NPI sentences. Each sentence was followed by a ‘yes/no’ comprehension question. Comprehension questions addressed various parts of the sentence to prevent the possibility that participants might develop superficial reading strategies whereby they extract only the information necessary to answer the comprehension question without fully interpreting the sentence.

3.2.3 Procedure

The same procedure was used as in Experiment 3.

3.2.4 Data Analysis

Data analysis followed the same steps as in Experiment 3.

3.2.5 Comprehension question accuracy

The mean comprehension question was 91%. There were no significant differences in accuracy between conditions.

3.2.6 Self-paced reading times

Figures 5 and 6 present the region-by-region condition means for sentences with pre-verbal *ever* (Figure 5) and post-verbal *ever* (Figure 6).

**Self-paced reading times: pre-verbal ‘ever’**

Pre-critical regions (R1-10) – pre-verbal *ever*: No significant effects for any of the experimental factors were observed in Regions 1-10.

Critical NPI regions (R11-19) – pre-verbal *ever*: There was a significant main effect of grammaticality at the region immediately following the NPI (R11), as reflected by a slowdown in the ungrammatical conditions relative to the grammatical condition ($\beta=-34.84$, SE=16.94, $t=-2.05$). Slower reading times for the no licensor condition persisted into Region 12, and a main effect of grammaticality was once again observed in Region 13 (R13: $t=3.10$). Region 11 also
showed a significant illusory licensing effect, as reflected by facilitated reading times for ungrammatical sentences with an intrusive licensor relative to ungrammatical sentences with no licensor ($\beta=-54.04$, $SE=24.00$, $t=-2.25$). The illusory licensing effect persisted into Regions 12-13 (R12: $t=-3.06$; R13: $t=-2.40$). No other significant effects for any of the experimental factors were observed in Regions 14-19.

**Self-paced reading times: post-verbal ‘ever’**

Pre-critical regions (R1-14) – post-verbal *ever*: No significant effects for any of the experimental factors were observed in Regions 1-14.

Critical NPI regions (R15-19) – post-verbal *ever*: At the NPI region (R15), there was a significant main effect of grammaticality, as reflected by a slowdown in the ungrammatical conditions relative to the grammatical condition ($\beta=-37.31$, $SE=14.33$, $t=2.60$). This effect persisted into Regions 16-17 (R16: $t=3.33$; R17: $t=-3.81$). There was no reliable evidence for illusory licensing at the NPI region or the subsequent regions, as reading times within the ungrammatical conditions did not diverge. No other significant effects for any of the experimental factors were observed in Regions 18-19.

Direct comparison of pre-verbal and post-verbal *ever*: We directly compared the processing dynamics of pre-verbal and post-verbal *ever* using a linear mixed-effects model that included the factors of NPI position and illusory licensing, and a fully-specified random effects structure. This analysis revealed contrasting illusory licensing profiles for pre-verbal and post-verbal *ever*, as reflected by a significant interaction between NPI position and illusory licensing ($\beta=-49.47$, $SE=17.79$, $t=2.78$).
3.2.7 Discussion

The results of Experiment 5 replicated the contrasting illusory licensing profiles for pre-verbal and post-verbal *ever*, which demonstrates that the contrast is robust across different measures. As in Experiment 4, pre-verbal *ever* showed a reliable illusory licensing effect, reflected in self-paced reading times as facilitated processing of an illicit NPI in the presence of an intrusive licensor. Post-verbal *ever*, by contrast, showed no such illusory licensing effect, as the presence of an intrusive licensor did not ease the processing of an illicit NPI.
One aim of Experiments 4 and 5 was to better understand the source of the contrasting illusory licensing profiles observed for *ever* and *any* in Experiments 2 and 3. We suggested several possible accounts for this contrast. Experiments 4 and 5 were designed to distinguish between accounts of the contrasting illusory licensing profiles that appeal to inherent lexical differences and selective repair on the one hand, and an account that appeals to positional differences on the other hand. The finding that a single NPI, *ever*, shows selective susceptibility to illusory licensing across different positions challenges the hypotheses that the contrast reflects inherent lexical differences between *ever* and *any* or selective repair of *ever*. Those hypotheses incorrectly predict illusory licensing to be a general property of *ever* in contexts with an intrusive licensor and do not predict variable susceptibility to illusory licensing as a function of the position of the NPI in the sentence. Rather, the results of Experiments 4 and 5 suggest that the selective nature of the illusion is a consequence of either the structural position of the NPI or extended time between the context containing the potential licensors and the NPI. We distinguish these alternatives in Experiment 6.

4. Experiment 6: The impact of time on illusory licensing

The aim of Experiment 6 was to test whether the selective nature of the illusion is a consequence of the structural position of the NPI or the time between the context containing the potential licensors and the NPI. To this end, we held constant the linear and structural position of the NPI *ever*, and manipulated the position of a parenthetical phrase to vary the time between the context containing the potential licensors and the NPI, as illustrated in (8).

(8) (As the editors mentioned) **no|the** authors [that **the|no** critics recommended for the assignment] have (as the editors mentioned) **ever** received a pay raise.

The parenthetical phrase in (8) extends the meaning of the main predicate, but it is not a primary constituent of the sentence. If the structural position of the NPI is critical for eliminating the illusion, then we should expect to see similar profiles for sentences with an intervening parenthetical phrase and sentences with a non-intervening parenthetical phrase, since the linear and structural position of the NPI is held constant. However, if elimination of the illusion is a
consequence of extended time between the intrusive licensor and the NPI, then we should expect to see the same modulation of the illusion seen for the previous comparisons, with a disappearance of the illusion for sentences involving an intervening parenthetical phrase.

4.1.1 Participants

Participants were 18 native speakers of English who were recruited using Amazon’s Mechanical Turk web-service. Participants were compensated $2.50. The experiment lasted approximately 15 minutes.

4.1.2 Materials

Experimental materials consisted of 36 sets of 6 items, which varied in terms of the presence and structural location of an NPI licensor (grammatical licensor / intrusive licensor / no licensor), and the position of a parenthetical phrase (non-intervening / intervening). All items contained a main subject NP that was modified by an object relative clause. As in Experiments 2-5, the NPI licensor no appeared either as the determiner of the main subject NP (grammatical licensor) or as the determiner of the relative clause subject (intrusive licensor), or was replaced with the definite determiner the (no licensor). The relative clause was always followed by the auxiliary have, which served to clearly mark the right edge of the relative clause, ensuring that participants would correctly construct a parse in which the intrusive licensor did not c-command the NPI. A four to seven word parenthetical phrase appeared either at the beginning of the sentence (non-intervening) or between the auxiliary and the NPI (intervening). The intervening position was chosen to ensure the intended main clause predicate attachment and interpretation of the parenthetical clause. In order to ensure that the parenthetical phrase did not specifically highlight either of the NP positions where the potential NPI licensors appeared, the parenthetical phrase never directly engaged or referred back to any component of the complex subject NP, and no component of the parenthetical phrase required access to this NP. Across all conditions the NPI ever appeared in the same position immediately before the main verb. An example set of the items is given in Table 4.
Table 4: Sample set of items for Experiment 6. NPIs and licensors are in bold.

4.1.3 Procedure

The same procedure was used as in Experiments 2 and 4.

4.1.4 Data Analysis

Data analysis followed the same steps as in Experiments 2 and 4.

4.1.5 Results

Figure 7 shows the proportion of ‘yes’ judgments for the 6 experimental conditions of Experiment 6. Results showed reliable detection of an unlicensed NPI, as grammatical sentences were more likely to be accepted than their ungrammatical counterparts (-intervening parenthetical: $\beta=3.09$, SE=0.55, $z=5.52$; +intervening parenthetical: $\beta=7.70$, SE=2.05, $z=3.74$). But judgments for the ungrammatical sentences sharply diverged. Contrasting illusory licensing profiles were observed for sentences with a non-intervening parenthetical phrase and sentences with an intervening parenthetical phrase, as reflected by an interaction between illusory licensing and parenthetical phrase position within the ungrammatical conditions ($\beta=-0.96$, SE=0.46, $z=-2.06$). Planned pairwise comparisons revealed that this interaction was driven by a significant illusory licensing effect for sentences with a non-intervening parenthetical phrase ($\beta=1.20$, 2023).
SE=0.43, \( z=-2.77 \), as participants were more likely to accept ungrammatical sentences with an intrusive licensor than ungrammatical sentences with no licensor. No such effect was observed for sentences involving an intervening parenthetical phrase.

![Figure 7: Experiment 6 speeded-acceptability judgment results percentage ‘yes’ responses for sentences with a non-intervening parenthetical phrase (left) and an intervening parenthetical phrase (right). Error bars indicate standard error of the mean.](image)

### 4.1.6 Discussion

In Experiment 6 we held constant the linear and structural position of the NPI *ever*, and manipulated the position of a parenthetical phrase (non-intervening vs. intervening) to vary the time between the context containing the potential licensors and the NPI. Sentences with a non-intervening parenthetical phrase showed a reliable illusory licensing effect, as comprehenders were more likely to accept ungrammatical sentences when an intrusive licensor was present. By contrast, sentences with an intervening parenthetical phrase showed no such illusory licensing effect, as the presence of an intrusive licensor did not increase the rate of acceptance of sentences that contained an illicit NPI. This pattern of results suggests that the time between the intrusive
licensor and the NPI is critical for eliminating the illusion, rather than the structural position of the NPI.

5. Experiment 7: Computational simulations of results

The results of the parenthetical phrase comparison revealed that extending the time between the intrusive licensor and the NPI can eliminate the illusion. However, it is possible that other factors, such as differences in passive memory dynamics that are unrelated to NPI licensing, could also make an important contribution to the illusory licensing effect. In Experiment 7 we used an explicit computational model of memory access to generate predictions about how these factors might impact NPI licensing and compared them to the behavioral data. To generate these predictions, we used a variant of the ACT-R (Adaptive Character of Thought – Rational) computational model of memory access described in Lewis and Vasishth (2005), Lewis, Vasishth, & Van Dyke (2006), and Vasishth et al. (2008).

5.1 The ACT-R computational model

ACT-R (Anderson et al., 2004; Anderson & Lebiere, 1998) is a cognitive architecture that is based on empirically motivated principles of working memory. It has served as the basis for a computational model of sentence processing (R. L. Lewis & Vasishth, 2005; R. L. Lewis et al., 2006) that has been applied to the task of NPI processing (Vasishth et al., 2008). In this model, the hierarchical structure of a sentence is represented as a set of disconnected ‘chunks’ in content-addressable memory (CAM; Kohonen, 1980; McElree, 2000; McElree, Foraker, & Dyer, 2003). Linguistic dependencies, such as those involving NPIs, are formed using retrieval cues that target specific licensing features of individual linguistic memory chunks. The defining property of CAM is that lexical and grammatical constraints provide the retrieval cues that allow direct access to the necessary licensing information in memory, obviating the need to search through extraneous representations. Chunks are encoded as a bundle of feature-value pairs called ‘content features’. Features that used for encoding and retrieval include lexical content (e.g., category information, morphological features, etc.), structural features (e.g., Case, grammatical role, etc.), and local hierarchical relations (e.g. sisterhood/complementation). Values for features may include symbols (e.g., ±singular, ±nominative, etc.) or pointers to other chunks in memory.
(e.g., NP₁, IP₃, etc.). A linguistic chunk may be retrieved from CAM for further processing or to build a linguistic dependency if the stored memory representation contains some features that overlap with the retrieval cues, i.e., linguistic information is retrieved based upon the content of the representations rather than their location in memory. Chunks are differentially activated based on the degree of similarity between their content features and the retrieval cues, and the total activation level of an individual chunk determines the probability with which that chunk is retrieved and restored to the current processing state.

Intrusion effects, such as those observed for NPI processing, can arise in ungrammatical contexts where the retrieval cues match, even partially, with other chunks in memory. According to Vasishth et al. (2008), encountering an NPI in the input initiates cue-based retrieval of a lexical licensor that matches both a semantic content feature, e.g., [+negation], and a structural feature, e.g., [+c-command]. Illusory NPI licensing, as a form of intrusion, arises when the structurally illicit, non-commanding licensor is spuriously retrieved due to partial overlap with the retrieval cue [+negation]. This type of retrieval error results in facilitated reading times for an otherwise unlicensed NPI, giving rise to a linguistic illusion.

This model is capable of generating precise quantitative fits to observed data, and it has been used to predict the magnitude of illusory NPI licensing effects in real-time comprehension (Vasishth et al., 2008). The dependent measure of ACT-R that is most important for the present purpose is the illusory licensing effect, which is derived from the predicted retrieval latencies and the predicted percentage of retrieval error. The illusory licensing effect measures the impact of the intrusive licensor on retrieval dynamics at the NPI. For measures of retrieval latency, the illusory licensing effect was computed by subtracting the predicted retrieval time of the NP with the highest probability of retrieval for conditions with an intrusive licensor from the corresponding measure in conditions without an intrusive licensor. The predicted retrieval error refers to the percentage of trials that resulted in the incorrect retrieval of the intrusive licensor. Following previous studies that use ACT-R to model retrieval in sentence comprehension (Dillon, Mishler, Slogget, & Phillips, 2013; R. L. Lewis & Vasishth, 2005; R. L. Lewis et al., 2006; Vasishth et al., 2008), we adopt the simplifying assumption that there is a monotonic relation between the reading times that are thought to partly reflect the timing of retrieval operations in real-time comprehension and the predicted retrieval latencies that are generated by the model.
5.1.1 ACT-R parameters

We tested a range of ACT-R parameter settings used in previous ACT-R research to ensure that the modeling results would be robust against variation in these parameters. The only exception to this approach was the scaling parameter \( F \), which was set at 1.4 across all simulations to ensure that the predicted retrieval latencies were on an appropriate time scale. 5,000 Monte Carlo simulations were run for each combination of parameters. Each trial included the full series of hypothesized retrievals, and each trial generated a predicted retrieval latency for the chunk with the highest probability of retrieval.

5.1.2 Materials

The empirical data of interest are the illusory licensing effects observed for the pre-/post-verbal comparisons (Experiment 2-5) and the parenthetical phrase comparison (Experiment 6).

5.1.3 ACT-R model results

Figure 8 shows the traces of the average ACT-R activation levels of the target, i.e. the head of the main subject NP, and intrusive licensor across a sentence involving the NPI \textit{any} in a post-verbal position (Experiment 3). The traces show that the target is reactivated immediately prior to the critical NPI retrieval, giving it a relatively large activation advantage over the intrusive licensor at the point of NPI licensing.\(^2\) This suggests an alternative explanation for the variable susceptibility to the illusion seen in the pre-/post-verbal comparisons: differences in passive memory dynamics due to a baseline activation bias for the target could selectively eliminate illusory licensing from the intrusive licensor for post-verbal NPIs. No such activation bias would be available for pre-verbal NPIs, since they appear before the verb, increasing susceptibility to illusory licensing.

\(^2\) It is generally assumed in ACT-R models of sentence comprehension (e.g., Vasishth et al., 2008) that thematic binding involves verbs and heads of arguments, rather than verbs and entire arguments, e.g., a complex NP. This is neither an obvious nor an innocent assumption in the current case, as it impacts the relative activation of the correct and intrusive licensor positions. It is also important to note that the retrieval at the relative clause verb targets the head for object binding, and that retrieval of the relative clause subject is not required for subject binding since it is still active in the lexical buffer when processing the verb. The results do not depend on this retrieval schedule, as simulations with and without retrieval of the relative clause subject predict similar profiles for NPI processing.
However, a comparison of the predicted and observed illusory licensing effects for the pre-verbal *ever* and post-verbal *any* comparison (Experiment 3) revealed that fluctuations of activations were not sufficient to capture the observed contrasts, as shown in Figure 9. ACT-R simulations predicted contrasting profiles, as reflected by a reduced illusory licensing effect for the post-verbal NPI *any*. However, this profile differs from the observed profile, which shows a disappearance of the illusory licensing effect for *any*.
Figure 9: Comparison of ACT-R predicted illusory licensing effects and observed illusory licensing effects for the pre-verbal *ever* and post-verbal *any* comparison (Experiment 3). Error bars indicate 95% CI.

Simulations of the parenthetical phrase comparison (Experiment 6) provided an additional test of the impact of passive memory dynamics on the illusory licensing effect. An important feature of the parenthetical comparison was that the parenthetical phrase did not specifically highlight either of the potential licensor positions. Given that the ACT-R decay parameter is uniform across all elements of a representation, the relative activation levels of the potential licensor positions should be preserved, predicting similar profiles for sentences with an intervening parenthetical phrase and sentences with a non-intervening parenthetical phrase, as shown in Figure 10. However, as in the pre-/post-verbal NPI comparison, the predicted profile differs from the observed profile, which shows a disappearance of the illusory licensing effect for sentences involving an intervening parenthetical. The differences between the predicted and observed profiles provides further evidence that the selective nature of the illusion cannot simply be due to differences in passive memory dynamics.
5.1.4 Discussion

ACT-R simulations showed that differences in passive memory dynamics can modulate the illusory licensing effect to some degree. However, comparisons to the empirical data revealed that such differences alone were not sufficient to capture the observed contrasts. In particular, ACT-R simulations did not predict the disappearance of the illusion that was consistently observed across our comparisons.

The modeling results of Experiment 7, taken together with the behavioral results of Experiments 1-6, inform our understanding of the scope and source of illusory licensing effects in two ways. First, they show that the NPI illusion is highly selective, occurring reliably only in
specific configurations. This selective profile is not predicted by existing accounts of illusory licensing effects, such as those proposed by Vasishth et al. (2008) and Xiang et al. (2009). These accounts attribute the illusion to general mechanisms that should apply whenever the parser attempts to license an NPI, and as such, they predict that the illusion should extend to a wide range of NPIs and contexts. However, the findings from the present study show that this is not the case. Rather, these findings suggest that it is the position of the NPI relative to the intrusive licensor that determines susceptibility to illusory licensing. Second, these results suggest that the selective nature of the NPI illusion must reflect changes across the representation beyond differences in passive memory dynamics, as these differences did not capture the observed contrasts.

As discussed earlier, existing studies on NPI illusions have probed for illusory licensing effects at different time points after the appearance of the NPI, and they have shown that sensitivity to the structural properties of a potential licensor grows as the lag from the NPI to the probe point increases. In contrast, across all of our comparisons, we held constant the point of probing relative to the NPI, and we found that sensitivity to the structural properties of a potential licensor also varied as a function of when the NPI appeared, such that sensitivity grew as the lag from the context containing the potential licensors increased. This variation suggests that some component of the NPI licensing process is not constant as a parse is extended. For example, the selective nature of the NPI illusion could reflect changes in the licensing conditions on NPIs, the access mechanisms, or the encoding of the context. We propose that whereas the licensing conditions on NPIs and the access mechanisms remain constant across a representation, the encoding of the context may vary over time, leading to variable susceptibility to illusory licensing based on when the NPI appears relative to the intrusive licensor. In particular, we suggest that the encoding of the hierarchical representation of the sentence in memory changes over time from a format where individual semantic and structural licensing features can be readily accessed for partial-matching to one where the semantic licensing features are no longer accessible independently from the position of those features in the structured sentence representation, preventing further partial-match illusory licensing effects. We develop this account further in the general discussion.
6. General Discussion

6.1 The source and scope of illusory NPI licensing effects

In the present study, we examined a linguistic illusion that involves illusory licensing of negative polarity items (NPIs), where comprehenders temporarily accept sentences with an illicit NPI in on-line measures, but later judge those same sentences as unacceptable after more reflection in off-line tasks. Experiments 1-3 provided the first direct comparison of the NPIs *ever* and *any*. Results revealed that while *ever* shows the illusion, *any* does not. We suggested that this contrast could reflect inherent properties of the NPIs or selective repair of *ever*, or that it could be a consequence of their differing sentential positions, e.g., pre-verbal *ever* vs. post-verbal *any*. Experiments 4 and 5 distinguished these alternatives by testing a single NPI *ever* in pre- and post-verbal positions. Results showed the same modulation of illusions seen for *ever* and *any*, favoring the positional account. Experiment 6 held constant the linear and structural position of the NPI *ever*, and manipulated the position of a parenthetical phrase to vary the time and distance between the NPI and the main subject. Results revealed that the illusion disappeared when a parenthetical phrase intervened between the potential NPI licensors and the NPI. Experiment 7 modeled these results, revealing that differences in passive memory dynamics were not sufficient capture the observed contrasts.

The results of the present study inform our understanding of the scope and source of linguistic illusions in comprehension as follows: First, the results show that illusory licensing effects are highly selective, occurring reliably only in specific configurations. This finding is not predicted by the accounts of NPI illusions proposed by Vasishth et al. (2008) and Xiang et al. (2009) and it implies that the illusion cannot simply be due to a noisy on-line implementation of the licensing mechanism. These accounts attribute the illusion to noisy on-line licensing mechanisms that should apply whenever a comprehender attempts to license an NPI. However, accounts that rely on a noisy licensing mechanism incorrectly predict that the NPI illusion should be rather general, which we found not to be the case. Second, the results of the present study show that the position of the NPI relative to the intrusive licensor determines susceptibility to illusory licensing. Across our comparisons, we consistently found that the NPI illusion disappeared when there was a greater lag between the intrusive licensor and the NPI.
6.2 Rapid representational change

Existing accounts of the NPI illusion, such as those proposed by Vasishth et al. (2008) and Xiang et al. (2009) have emphasized that NPI licensing is a function of (i) the licensing conditions on NPIs, (ii) the access mechanisms, and (iii) the encoding in memory of the prior sentence context. Under these accounts, the illusion is understood as a kind of partial-match effect, and suggests that on-line processing mechanisms can access semantic licensing features such as negation independently from the position of those features in the structured sentence representation. Importantly, these studies have probed for illusory licensing effects at different time points after the appearance of the NPI, and they have shown that the sensitivity of the access mechanisms to the structural properties of a potential licensor grows as the lag from the NPI to the point of sampling increases. That is, according to these previous studies, susceptibility to illusory licensing is impacted by the amount of time that a comprehender has had to process the NPI, with more time yielding greater grammatical accuracy. The contrast in illusory licensing effects between tests that probe immediately after the appearance of the NPI and tests that probe at a later point can be captured by holding constant all components of the licensing function, i.e. (i)-(iii) above, while assuming that the access mechanisms are noisy, and hence yield more sensitive results over time with repeated access attempts using the same mechanism. These accounts predict that variation in the time or position of when the NPI is introduced should have no impact, given the assumption that the components of the licensing function (i.e., the licensing conditions, the access mechanisms, and the encoding of the context) are constant as a parse is extended.

In contrast to these previous studies, we focused on the time that elapses between the context containing the potential licensors and the introduction of the NPI. For example, we held constant the point of sampling relative to the NPI, and we consistently found that sensitivity to the structural properties of a potential licensor grew as the lag from the intrusive licensor increased, leading to a disappearance of the illusory licensing effect during on-line processing. This finding suggests that some component of the licensing function is not constant across the representation. For example, the licensing conditions on NPIs could vary based on when the NPI is introduced. We believe this to be an unlikely possibility, especially given the results of parenthetical phrase comparison (Experiment 6). In this comparison, the NPI always appeared in exactly the same linear and structural position, yet we observed differential sensitivity to the
structural properties of a potential licensor from the same position. This suggests that the structural position of the NPI is not critical for eliminating the illusion, and hence it is unlikely that the variable susceptibility to the illusion is due to processes that are initiated when the NPI is introduced.

Another possibility is that the access mechanisms vary based on when the NPI is introduced. Recent research on the memory operations that are used to query linguistic structure suggests that comprehenders build complex hierarchical representations as they process a sentence, but that they have different ways of navigating those representations to build linguistic dependencies. For example, hierarchical representations in memory can be navigated either using a content-addressable retrieval, which relies on a combination of structural and non-structural information to query linguistic structure in memory, or using a structure-guided search operation (see Dillon, 2011; Dillon et al., 2013; Phillips et al., 2011, for discussion). We suggest that the use of multiple access mechanisms for NPI licensing is unlikely, again based on the findings from the parenthetical phrase comparison. If, for example, parenthetical phrases could trigger the use of a structure-guided access strategy, then we would expect to see grammatically accurate processing for sentences involving a non-intervening parenthetical phrase. However, this prediction was not borne out in the data, as sentences with a non-intervening parenthetical phrase showed a robust effect of illusory licensing.

A third possibility that could impact licensing is decay or locality. Recent research on distance effects in on-line processing has shown that factors such decay and the number of intervening words are a key determinant of dependency resolution difficulty, with greater processing difficulty observed as the distance or number of words that intervene between dependent elements increases (Gibson, 1998, 2000; Gibson & Thomas, 1999; Grodner & Gibson, 2005; Hawkins, 1994). This hypothesis predicts increased errors of illusory licensing across increased distances. However, the findings from the present study show the opposite effect, as errors of illusory licensing disappeared as the distance from the intrusive licensor to the NPI increased.

We argue that whereas the licensing conditions on NPIs and access mechanisms are constant, the encoding of the context changes as a parse is extended. Specifically, we argue that the encoding of the hierarchical sentence representation in memory changes over time from a format where individual semantic and structural licensing features can be readily accessed for
partial-matching to one where the semantic licensing features are no longer accessible independently from the position of those features in the structured sentence representation. For example, as comprehenders process a sentence, they may periodically consolidate the independent features of an expanding hierarchical constituent structure into a single, unitized encoding in memory. This feature-integration process binds together the independent semantic and structural features to create a compressed encoding of the hierarchical constituent structure. As such, partial-matching on individual features in memory is no longer possible, and the representations that encode licensing information must be recovered holistically since the individual constituent features are no longer transparently accessible. This shift in the representational format prevents further partial-match illusory licensing errors, and hence yields greater processing accuracy.

This type of change in the representational format of sentences in memory may be supported by a particular type of memory chunking called conceptual chunking (Halford, Cowan, & Andrews, 2007; Halford, Wilson, & Phillips, 1998), which has been explicitly characterized in models of analogical reasoning (e.g., Halford et al., 1994). Conceptual chunking involves compressing representations into a unitary representation in memory in order to reduce their dimensionality and ease their processing load within a capacity-limited short-term working memory store. Importantly, the individual components of a conceptual chunk function as a whole in a relational structure. The cost of compression, however, is that the individual components are no longer independently accessible.

A key property of conceptual chunking is that it compresses a representation into fewer variables, but maintains explicit relations between those variables, as opposed to simple associations. It is possible that some type of conceptual chunking, which has been shown to play a fundamental role in cognitive reasoning tasks (Halford et al., 2007), may be extended to dynamically encode the hierarchical structure of a sentence. Under this view, conceptual chunking as a form of representational change in real-time sentence comprehension may arise as a natural consequence of the capacity limits on short-term working memory. For example, it has long been recognized that the capacity of short-term working memory is extremely limited (e.g., Baddeley, 1986; Broadbent, 1958; Cowan, 2000; Garavan, 1998; Jonides et al., 2008; R. L. Lewis, 1996; McElree, 1998, 2001, 2006; McElree & Dosher, 1989; Miller, 1956; Oberauer, 2002; Verhaeghen, Cerella, & Basak, 2004, but cf. Caplan & Waters, 2013). Conceptual
chunking in sentence comprehension can allow the representational resources of short-term working memory to be used in a highly information-efficient manner. In effect, the inability to access the internal contents of a chunk increases memory capacity, and reduces processing load to allocate more cognitive resources to the task of attending to the incoming input.

Conceptual chunks differ sharply from the conceptualization of chunks in leading models of memory retrieval in sentence processing (e.g., R. L. Lewis & Vasishth, 2005; R. L. Lewis et al., 2006; Vasishth et al., 2008). In the ACT-R model of sentence comprehension as described in Lewis and Vasishth (2005), the syntactic structure of a sentence is represented as a set of disconnected chunks, and cue-based retrieval operations are used to build hierarchical relations between those chunks. Chunks are encoded as a bundle of content features, but the individual features are independently accessible for on-going retrieval-based parsing operations (see Section 4.1 above for further description of this model). As such, the transparency of a chunk is defined at the level of the features of the chunk (see Caplan & Waters, 2013, for further discussion). One consequence of this transparency is that retrieval operations can target specific, individual features of a chunk, and a chunk can be retrieved even if it only partially overlaps with the retrieval cues, leading to intrusion effects that take the form of illusions of grammaticality. In contrast, conceptual chunks do not provide easy access to the internal content-features of a chunk, which prevents partial-match illusions.

There are several mathematical models of feature binding and compression that could be extended to explicitly characterize the computational character of representational change, including tensor-product variable binding (e.g., Smolensky, 1990), Spatter Code (e.g., Kanerva, 1994, 1996, 1997), vector-symbolic architectures (Gayler, 2003; Sommer & Kanerva, 2006), holographic reduced representation (e.g., Plate, 1991, 1994, 2003), and context-dependent thinning (e.g., Rachkovskij & Kussel, 2001). A feature shared by these models is that linguistic features and combinatorial structures are represented as high-dimensional vectors that are manipulated by operations that generate new high-dimensional vector representations (see Kanerva, 2009, for a review). For example, Plate (1991, 1994, 2003) proposed a model of “holographic reduced representations” (HRRs) in which the binding of two vector representations in hyper-dimensional space can be described as a compression of their tensor product to a vector representation that is of the same dimension as each of the sub-components, i.e. the size of the representation does not increase as more structure is added (see also Hinton,
This property is potentially important for cognitive models of feature binding in language comprehension especially given the stringent limit on the amount of information that can concurrently occupy working memory. Crucially, for the purpose of capturing the effects of representational change in sentence comprehension, an HRR is resistant to the kind of partial-match effects that can give rise to linguistic illusions: feature binding within the HRR framework creates a representation that is completely dissimilar to any of its bound features, and since the sub-component features are no longer transparently accessible, the representation must exhibit an all-or-none match to the retrieval probe in order to be retrieved from memory. However, there are numerous mathematical algorithms for generating reduced representations, such as convolution (Plate, 1991, 1994, 2003), element-wise multiplication (Gayler, 2003; Kanerva, 1994, 1996, 1997), and permutation-based thinning (Rachkovskij & Kussel, 2001). An important task for future research is to verify the predictions of the different feature binding methods and to explore their empirical consequences.

In addition to understanding how representational change might be implemented, it is also necessary to understand what triggers representational change in real-time comprehension. Representational change could be a consequence of time, specific linguistic triggers, or limits of memory capacity. For instance, the results of the parenthetical comparison suggest that representational change could be triggered by extended time or increased distance between the context containing the potential licensors and the NPI. In this comparison, we manipulated the position of a parenthetical phrase to vary the time/distance of the NPI from the intrusive licensor, while holding the linear and structural position of the NPI constant, and we found that the illusion disappeared when there was a greater distance between the NPI and the intrusive licensor. Alternatively, the trigger of representational change might not be reducible to the passage of time, but rather representational change could be triggered by specific linguistic elements. For instance, an intervening parenthetical phrase could force the parser to ‘wrap-up’ and compress the encoding of the current object, e.g. the main subject NP, before processing the relatively independent unit that is the parenthetical phrase. Similarly, the results of the ever/any comparison in Experiments 2 and 3 suggest that processing the lexical main verb may trigger a change in the representational format. It is possible, for example, that the representational format of the complex subject NP cannot be fully unitized until after it has been thematically integrated with the verb. After thematic binding with the verb, the feature composition of the subject NP is...
fully determined, and the parser can then consolidate the hierarchical representation into a unitized encoding. A more general possibility is that the capacity limits of working memory force the parser to periodically consolidate the independent features of an expanding hierarchical constituent structure into a single, unitized encoding in memory in order to decrease processing load and conserve memory resources. However, the experiments presented here were not designed to distinguish these alternatives. We leave further investigation of possible triggers of representational change to future research.

6.3 Extensions and implications of two-stage encoding

The two-stage encoding scheme that we have proposed is similar in some regards to other two-stage parsing models, such as those proposed by Frazier and J. D. Fodor (1978) and Kimball (1973). Much as in our two-stage encoding scheme, in these models the syntactic analysis of a sentence is built in two stages, with one stage temporally prior to the other (see also Abney, 1991; Fodor, Bever, & Garrett, 1974; Whitney, 2004; but cf. Marslen-Wilson & Tyler, 1980). Although the models differ with respect to the nature of the units that are shunted between the two stages, the motivation for the division of parsing into two stages is based on assumptions about capacity limits on working memory. More generally, a property common to both two-stage models of language comprehension and our two-stage encoding scheme is that the division of labor into two temporally-ordered stages determines restrictions on the information that is available at each stage.

The two-stage encoding scheme that we have proposed may also provide independently motivated explanations for two puzzles in language processing: The first puzzle concerns the unexplained fact that representations that are more structured actually make smaller demands on memory storage space (Marks & Miller, 1964; Miller & Isard, 1963; see also Frazier & Fodor, 1978). This implicates the use of sophisticated compression operations that are dynamically applied to hierarchical representations in order to keep the demand on working memory within its limits as a parse is extended. The process of feature consolidation that we propose may be one way to implement the type encoding compression that is required to satisfy the capacity constraints on working memory.

The second puzzle concerns the source of the contrasting intrusion profiles observed for subject-verb agreement and anaphora. Recent research on the on-line implementation of
agreement constraints has revealed a strikingly uneven profile. The processing of subject-verb agreement, for example, displays strong intrusion effects (Bock & Miller, 1991; Clifton, Frzier, & Deevy, 1999; Dillon et al., 2013; Eberhard, Cutting, & Bock, 2005; Franck, Vigliocco, & Nicol, 2002; Pearlmutter, Garnsey, & Bock, 1999; Staub, 2010; Wagers et al., 2009), but reflexive anaphors, which are also subject to a morphological agreement constraint, show no such intrusion effects. Previous studies of reflexive anaphors have either found no effects of intrusion from structurally-illicit antecedents (Clifton et al., 1999; Dillon, 2011; Dillon et al., 2013; Nicol & Swinney, 1989; Sturt, 2003; Xiang et al., 2009), or they have found inhibition effects (Kennison & Trofe, 2003; Patil, Vasishth, & Lewis, 2011; Sturt, 2003, but cf. Cunnings & Felser, 2012, and King, Andrews, & Wagers, 2012). The source of the contrasting intrusion profiles between agreement and reflexive dependencies remains unclear. Dillon et al. (2013) suggest that the contrasting profiles reflect differences in the underlying grammatical organization of two dependencies, such that agreement features are deployed as retrieval cues in the processing of subject-verb agreement, but not in the processing of reflexives. They also acknowledge that the contrasting intrusion profiles are consistent with models that adopt qualitatively different memory access mechanisms for different dependencies (see Dillon, 2011; Dillon, submitted; Phillips et al., 2011, for discussion). The account of representational change that we have proposed may provide a possible alternative explanation for the contrasting intrusion profiles seen for subject-verb agreement and reflexive dependencies. Nearly all previous demonstrations of the lack of intrusion for reflexives involve a reflexive in a post-verbal position. Recall that under our account, susceptibility to illusory licensing is impacted by whether the dependent element appears before or after the representational format of the sentence has been consolidated into a unitized encoding, which may be linked to the lexical main verb. A possible alternative explanation for the robust immunity to intrusion observed for reflexives might be that previous studies introduced the reflexive after the main verb that triggers representational change through feature integration, inadvertently probing a representation of the sentence that was immune to partial-matching.3 The generality of representational change and

3 Kush, Lidz, and Phillips (2012) showed that Hindi reciprocals in a pre-verbal position were robust against illusory licensing from intrusive antecedents. However, it is possible that multiple levels of embedding in their materials forced the parser to compress the sentence encoding before the reciprocal was encountered, eliminating the possibility for partial-match intrusion. Conversely, King et al. (2012)
feature-integration in sentence comprehension is an important question, and future work will examine how these processes impact the comprehension of other dependencies, such as those involving reflexive anaphors, and other linguistic feature systems.

6.4 Relating feature-integration in language and vision

Two-stage encoding schemes are also observed in other domains of cognition, such as visual processing, leading to changes in representational format that are parallel to what we have seen in the domain of language comprehension. For example, just as in language comprehension, the encoding of visual representations is established in two stages, with one stage temporally prior to the other, and this division determines restrictions on the information that is available to each stage. In this section, we briefly discuss the parallels between these two-stage encoding schemes.

In visual cognition, there is an initial stage of processing during which individual object features such as shape and color are encoded independently of each other. This first stage of encoding is followed by a feature-integration stage, where the separate, independently accessible features are consolidated into a single, unitized encoding of the object in visual memory. This two-stage encoding scheme in vision is explicitly characterized by the feature-integration theory of attention (Treisman & Gelade, 1980; Treisman & Schmidt, 1982; Treisman et al., 1977; see also Chun & Potter, 2000; Holcombe & Clifford, 2012; Treisman, 1996; Wolfe, 2007, 2012). Evidence for a two-stage model of visual encoding comes from errors of illusory conjunctions. For example, Treisman and Schmidt (1982) conducted an experiment to show that the individual features of an object are analyzed independently of each other in early visual processing. In their experiment, participants were briefly shown a picture involving four colored shapes (e.g., large brown triangle, small pink triangle, large yellow circle, small blue circle) that were placed between two black digits (e.g., 6 and 7). After the picture was presented, participants were asked to report all that they had seen at a cued location in the picture. Treisman and Schmidt reasoned that if the features of shape, color, and size are separable in the initial stage of visual processing,

observed an illusory licensing effect for reflexives that were embedded in a post-verbal prepositional phrase (PP). However, a reflexive in a PP may be associated with different licensing conditions than a reflexive in direct object position. Further research is needed to better understand the licensing conditions for predicate-separated reflexives.
then colors should be interchanged freely between large and small shapes and between shapes of the same size. They found that in 18% of trials, participants made conjunction errors, where they reported a combination of features from two different stimuli from a single display. Treisman and Schmidt interpreted this finding as evidence for an initial stage of perceptual processing where individual features are encoded independently of each other, followed by a feature-integration stage where features may be incorrectly combined, leading to illusory conjunctions (see also Holcombe & Clifford, 2012; Wolfe, 2012, but cf. Di Lollo, 2012). Crucially, however, parallel to our finding that the manipulation of additional factors such as time or intervening material led to a disappearance of the NPI illusion, Treisman and Schmidt also found that the manipulation of additional factors such as attention led to a disappearance of illusory conjunctions in the second stage of encoding. This parallel suggests one way in which language and visual cognition may be related (Bloom, Peterson, Nadel, & Garrett, 1999), and it raises the possibility that the feature-integration mechanisms that are deployed in these two domains of cognition may be variants or specializations of a common cognitive mechanism that is used more generally.

7. Conclusion

In this study, we investigated the source and scope of NPI illusions in real-time sentence comprehension. Existing accounts of the illusion claim that the illusion reflects a noisy on-line implementation of the licensing mechanism, and the resulting theories have emphasized that increases in sensitivity to the structural properties of a potential licensor reflect changes that happen as more time is allowed after licensing. In contrast, we consistently found across several closely controlled comparisons that (i) the NPI illusion is highly selective, and (ii) the position of the NPI relative to the intrusive licensor strongly modulates the illusion. These results are not predicted by existing accounts, and they imply that the illusion cannot simply be due to a noisy licensing mechanism. Rather, we suggested that the selective nature of the illusion reflects changes over time in how hierarchical representations are encoded in memory. Contrary to the widespread assumption that the format of hierarchical representations remains constant throughout a parse, we argued that hierarchical encodings change from a format where individual features can be readily accessed to one where they are not accessible independently from the
position of those features in the structured sentence representation. Specifically, we proposed that throughout incremental comprehension, the parser consolidates the independent features of an expanding hierarchical sentence representation into a single, unitized encoding in memory. This shift in the representational format prevents partial-match illusory licensing errors, and hence yields greater processing accuracy. In sum, the findings from this study revealed that the encoding of hierarchical structure is not fixed over time and that variable susceptibility to linguistic illusions is a consequence of changes in the representational format of hierarchical encodings in memory.

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