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Comprehending the impossible: what role do selectional restriction violations play?

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Abstract

To elucidate how different kinds of knowledge are used during comprehension, readers' eye movements were monitored as they read sentences that were: plausible, impossible because of a selectional restriction violation, or impossible because of a violation of general world knowledge. Eye movements on the pre-critical, critical, and post-critical words evidenced disruption in the selectional restriction violation condition compared to the other two conditions. These findings suggest that disruption associated with reading about impossible events is not directly determined by how impossible the event seems. Rather, the relationship between the verb and arguments in the sentence seems to matter. These findings are the strongest evidence to date that processing effects associated with selectional restrictions can dissociate from those associated with general world knowledge about events.

Keywords

language comprehension; plausibility; eye tracking; sentence processing; reading

The role of world knowledge in language comprehension has been hotly debated (e.g. Frazier, 1987; McRae, Ferretti, & Amyote, 1997). Modular theories (e.g. Frazier, 1987) proposed that the comprehension system initially uses knowledge available within specialized modules, and only later uses general world knowledge. Some theories argued that the lexicon is such a module, and that one kind of knowledge represented in that module is a verb's **selectional restrictions** (Chomsky, 1965; Katz & Fodor, 1963), namely the basic set of semantic features a verb requires of its arguments. Under a selectional restriction account, the verb *drink* has a selectional restriction for an animate agent, capturing the intuition that *John drank the tea* and *The dog drank the tea* are both interpretable, if differently consistent with expectations derived from world knowledge, but *The rock drank the tea* is uninterpretable. There is now convincing evidence against a modular lexicon (Duffy, Morris, & Rayner, 1988; Jackendoff, 2002; Nieuwland & van Berkum, 2006; *inter alia*), and considerable evidence for early effects of world knowledge in comprehension (e.g. Bicknell, Elman, Hare, McRae, & Kutas, 2010), but it is still an open question whether

something like selectional restrictions might play a different role from general world knowledge in comprehension (e.g., Kuperberg, 2007).

Operationalizing selectional restrictions is not straightforward. In fact, Jackendoff (2002) and others have argued that there is no way to determine whether any given semantic feature is a selectional restriction or part of world knowledge. Still, experimental work using various working definitions of selectional restrictions hints that they may have greater or different ramifications for language processing than other kinds of semantic anomalies do (e.g., Kuperberg, 2007; Warren & McConnell, 2007). In the current paper, we operationalize selectional restrictions as cases in which a given verb sense places a basic semantic requirement on an argument, regardless of whether that requirement is animacy, sentence, state of matter, or some other semantic feature.

Some evidence suggests that selectional restrictions and world knowledge are used similarly in comprehension. Hagoort, Hald, Bastiaansen and Petersson (2004) compared ERPs and fMRI activity to sentences that were true vs. false vs. contained a semantic anomaly. The anomalies they used were much like selectional restriction violations (SRVs) but didn't involve a verb-argument relation (e.g. The Dutch trains are *yellow/white/sour* and very crowded). Activity was almost identical for the world-knowledge and semantic-anomaly conditions, with only oscillatory EEG responses differing. They concluded that the brain does not distinguish between world knowledge and lexical semantic information.

But there is also evidence suggesting that processing may be different for violations of selectional restrictions versus world knowledge. In contrast to the Hagoort et al. (2004) results, Warren and McConnell (2007) reported earlier and greater eye movement disruption to sentences with SRVs than to sentences describing extremely unlikely, but possible, events. Disruption to SRVs appeared as early as the first fixation on the anomalous word, suggesting that SRVs were detected in initial stages of processing. Disruption to extremely unlikely events did not become apparent until measures that included regressions and re-reading. Selectional restrictions also seem more robust to contextual influence than world knowledge. Paczynski and Kuperberg (2012) showed that expectations based only on world knowledge, but not on selectional restrictions, could be overridden by semantic association with preceding words between 300–500ms, and that only violations of selection restrictions led to prolonged costs in processing between 500–800ms (the so-called semantic P600 effect, see Kuperberg, 2007, for other examples of such prolonged processing costs to selection restriction violations). In Warren, McConnell, and Rayner (2008), a supportive context (e.g. a cartoon) failed to eliminate early disruption associated with the initial encounter of an SRV, though it mitigated slightly later disruption. This contrasts with findings in which supportive context largely eliminates difficulty associated with world-knowledge violations (e.g. Filik, 2008).

This debate has important ramifications for the comprehension system, even if evidence of early selectional-restriction-specific influences does not entail modularity. Evidence of separable and early selectional-restriction-specific influences on comprehension could be consistent with interactive experience-based models in which event knowledge immediately influences comprehension (e.g. McRae & Matsuki, 2009), and it would be informative about

the kinds of information these systems represent. Within models like these, selectional restrictions could be implemented as coarse-grained semantic abstractions generated on the basis of experience with particular verb senses and events. Selectional-restriction-specific influences on comprehension, then, could be evidence that comprehenders calculate such abstractions and then use them to either predict or filter coarse-grained semantic properties of a verb's arguments (e.g. Kuperberg, 2013; Paczynski & Kuperberg, 2012; Warren & McConnell, 2007).

As reviewed above, the available evidence for selectional-restriction-specific influences is mixed. However, it is also weak. In Hagoort et al (2004), the lexical-semantic violations were not verb-related SRVs. In Warren and McConnell (2007) and Paczynski and Kuperberg (2012), the conditions with SRVs were the only conditions that described impossible events. To determine whether selectional restrictions play a role in language processing, it is critical to disentangle the contributions of event impossibility from the presence of an SRV, because event impossibility can be determined from general world knowledge without the need for any verb- or event-related coarse-grained semantic abstraction. The current study attempts to do this by comparing eye movements to baseline sentences, impossible sentences without an SRV, and impossible sentences with an SRV. If general world knowledge, operationalized here as the knowledge that a particular event is possible or impossible, drives comprehension, then the two impossible conditions should show similar patterns of disruption when compared to the baseline. If coarse-grained semantic abstractions play a role in comprehension, then the impossible SRV condition should show earlier and more disruption than either of the other two conditions.

Method

Participants

Sixty University of Pittsburgh undergraduates participated for course credit. All were native English speakers with normal or corrected-to-normal vision.

Apparatus

An Eyelink 1000 eye-tracker monitored the gaze location of participants' right eye every millisecond. Participants viewed stimuli binocularly on a monitor 63 cm from their eyes; approximately 3 characters equaled 1 degree of visual angle.

Materials

There were 30 items with three conditions (possible, impossible/no SRV, impossible/SRV). A list of the items is included in Appendix A. The target noun was the object/patient of the sentence (*backpack*, underlined below), and the first point at which the violation was apparent in the impossible conditions.

- 1a)** Corey's hamster explored a nearby backpack and filled it with sawdust.
(possible)
- 1b)** Corey's hamster lifted a nearby backpack and filled it with sawdust.
(impossible/no SRV)

- 1c) Corey's hamster entertained a nearby backpack and filled it with sawdust.
(impossible/SRV)

Each sentence contained a noun phrase, followed by a main verb, determiner, adjective, and the target noun, which was at least five characters long to increase the likelihood that it would be fixated, and was followed by at least two additional words. The only word that varied across conditions was the verb. In the possible condition, the described event was possible, though not very likely or expected. Examples of possible events were a puppy licking a lawnmower or a skunk spraying a bulldozer or a baby touching a canoe. We chose events that were not very likely or expected because increased predictability, production likelihood, and plausibility all speed eye movements in reading (e.g. Ehrlich & Rayner, 1981; Matsuki, Chow, Hare, Elman, Scheepers, & McRae, 2011; Rayner, Warren, Juhasz, & Liversedge, 2004), and we wanted the comparison between the possible and impossible conditions to be likely to reflect possibility. The event in the impossible/no SRV condition was impossible because the agent could not carry out the verb's action on the patient (e.g. hamsters can lift things and backpacks can be lifted, but hamsters cannot lift backpacks). In the impossible/SRV condition, the patient did not have the necessary semantic features to satisfy the verb (e.g. backpacks, not being sentient, cannot be entertained). Most of the verbs used in the SRV condition were object-experiencer verbs, which have been associated with longer reading times than non-psych verbs in self-paced reading experiments (e.g. Brennan & Pykkanen, 2010). However, in the Brennan and Pykkanen study, which tested sentences with verb-determiner-adjective-noun sequences just like the current study, these longer reading times were localized at the verb and the article and resolved by the adjective. Given that our target word was the noun following the adjective, it seems likely that any verb-related difficulty would have been resolved before our target word.

The items were pre-tested in two questionnaire studies. In each, conditions were counterbalanced across three presentation lists using a Latin square design. Data were analyzed with linear mixed effects models (Baayen, 2008), using the lme4 package (Bates, 2005; ver. .999999-2) in the R statistical computing package (R Development Core Team, 2013; ver 3.0.1). Models included participants and items as crossed random effects. Following Barr, Levy, Scheepers, and Tily (2013), we included random slopes for all critical (non-nuisance) factors. Given issues regarding generating p-values in models with random slopes, fixed-factor reliability was determined by using a likelihood ratio test to compare models that included versus dropped the fixed factor in question (except for the logit models, which do provide p-values).

The first study evaluated possibility, to verify the possibility manipulation implemented in the items. Twenty-one participants who did not participate in the eye-tracking experiment read items truncated after the target word (e.g. *Corey's hamster explored a nearby backpack*) and judged whether they described possible (scored as 1) or impossible (scored as 0) events.ⁱ Average scores were: possible = .848, impossible/no SRV = .167, and impossible/SRV = .057. Given the very low incidence of 1 responses in the impossible/SRV

ⁱWe did a binary choice norming of impossibility instead of using a scale to minimize the likelihood that participants would conflate plausibility and possibility. Note that variability in possibility norms (i.e. items not being consistently rated 1 or 0) is not unusual (e.g. Warren & McConnell, 2007).

condition, standard models failed to converge. Therefore we converted the data to empirical logits grouped by participantsⁱⁱ, and ran a model with the impossible/noSRV condition as the reference level in a treatment contrast. The possible vs. impossible/noSRV contrast ($\beta=3.47$, $t=13.60$) was reliable according to a likelihood ratio test ($\chi^2(1)=45.90$, $p < .001$), but the impossible/noSRV vs. impossible/SRV contrast ($\beta=-.35$, $t=-1.24$) was not ($\chi^2(1)=1.24$, $p = .27$). This pattern indicated that the possibility manipulation was successful; however, even if the small difference between the two impossible conditions was real, there was critically a large difference between the possibilities of the possible and impossible conditions and a very small difference between the two impossible conditions.

The second study tested whether the stimuli were equally natural before the target word was encountered, as prior unnaturalness could spill over onto the processing of the target word. 23 different participants rated the naturalness of the items truncated immediately before the target word (e.g. *Corey's hamster explored a nearby...*) on a scale of 1 (very natural) to 5 (very unnatural). Average scores were: possible = 2.20, impossible/no SRV = 2.43, and impossible/SRV = 2.63. R's default treatment contrast indicated the following effects: possible vs. impossible/no SRV ($\beta=.22$, $t=1.56$) and possible vs. impossible/SRV ($\beta=.42$, $t=3.34$). A likelihood ratio test indicated that there was a reliable overall effect of condition ($\chi^2(2)=9.56$, $p < .009$). These naturalness ratings were therefore included as a nuisance factor in analyses.

The 30 experimental items were combined with 36 items from an unrelated experiment investigating the processing of conjunctions and disjunctions in semantically normal sentences (e.g. *Katy bought either a new TV or a fancy pair of speakers with her paycheck.*) and 64 semantically normal, syntactically straight-forward filler items (e.g. *Karen couldn't find the car keys even though she looked everywhere.*), many of which included animals and/or proper names. Conditions were counterbalanced across three presentation lists using a Latin square design. Each participant thus read 20 impossible sentences distributed among 110 natural sentences. After 32 of the filler items, participants answered a yes/no comprehension question. Approximately half required a "yes" response. Presentation order was randomized.

Procedure

The experiment lasted approximately 35–45 minutes. Chin and forehead rests minimized head movements. Participants were asked to read normally and were told that after some sentences they would be asked a yes/no comprehension question. The tracker was aligned and calibrated before and during the experiment as necessary.

Results

Analyses were conducted over a pre-target region (the determiner and adjective preceding the target noun), the target noun, and a post-target region. This post-target region was either the word following the target noun, or if that word was less than five characters and thus

ⁱⁱWe ran a by-participants analysis because the aim of this statistical test is to see if the differences in exactly this population of items used in the experiment would be likely to generalize to new sets of participants.

likely to be skipped rather than fixated, the region was the two words following the target noun.

Comprehension rates were high ($M = 93\%$); all participants were above 80% accurate on comprehension questions. Approximately 5% of trials were excluded from analysis due to track losses or blinks in the target regions. The target regions were fixated on 88% of trials during the first pass across all conditions; fixation rates were similar across conditions (pre-target region: 91%-93%, target region: 88%-91%, post-target region: 81%-84%).

The following eye-movement measures were computed (Rayner, 1998): (1) the duration of the *first fixation* on a region during first pass readingⁱⁱⁱ, (2) the sum of all fixations on a region during first pass reading (*gaze duration*), (3) the sum of all fixations from entering a region during first pass reading until leaving it to the right, including any regressive fixations (*go-past*), (4) the percentage of times a regression was launched from a region during first pass reading (*first-pass regressions out*), and (5) the sum of all fixations on a region (*total time*). The first four measures reflect first-pass processing; although go-past time includes rereading, it indicates how long it took to move past a given region in the text during first pass reading. All duration-based measures were natural log transformed to reduce skewness and trimmed at three standard deviations above the mean to eliminate outliers. This cut-off excluded less than one percent of the data for every measure in all analysis regions, except go-past times in the post-target region, for which one percent was lost. Running identical analyses to those reported below on the untrimmed data did not change the pattern of results. Possibility and SRV contrasts used the impossible/no SRV as the reference condition, such that the possibility factor tested whether the possible and impossible/no SRV conditions differed, and the SRV factor tested whether the impossible/SRV condition differed from the impossible/no SRV condition.

Pre-target region

Models analyzing the pre-target region (the determiner and adjective preceding the target noun) included as fixed factors: average naturalness ratings at the pre-target region (centered), the length of the word preceding the pre-target region^{iv} (centered), SRV, and possibility. Length of the preceding word and naturalness at the pre-target region were included as nuisance factors because they could affect the duration of fixations in the pre-target region (Rayner, 1998). There was no reason to expect interactions among any of the factors, so none were built into the models. The models also included random intercepts and random slopes for SRV and possibility, for both participants and items.

Table 1 reports means for untransformed measures on the pre-target region. First fixation, gaze duration, and first pass regressions out were not reliably affected by the experimental manipulation. SRV marginally affected go past ($\beta = .087$, $t = 2.68$; $\chi^2(1) = 2.80$, $p = .09$), but reliably affected total time ($\beta = .166$, $t = 4.07$; $\chi^2(1) = 14.37$, $p < .001$). Possibility was not reliable in any measure.

ⁱⁱⁱA fixation on a region is considered to be during first pass reading only if the eyes have just entered the region from the left and that region had not previously been skipped.

^{iv}The word preceding the pre-target region was almost always a verb, but in a few cases it was a particle (e.g. *relied on*).

Target word

Table 2 reports means for untransformed measures on the target word. As fixed factors, models analyzing the target region included: average naturalness ratings at the pre-target region (centered), SRV, and possibility. Models again included random intercepts and random slopes for SRV and possibility, for both participants and items.

First fixation duration on the target word showed an effect of SRV ($\beta=.047$, $t=2.40$) that was reliable ($\chi^2(1)=5.54$, $p=.02$). However, given that the mean for the possible condition fell right between the two impossible conditions, this is likely not a real effect of disruption associated with a SRV. Gaze duration on the target word showed a marginal effect of SRV ($\beta=.049$, $t=1.85$; $\chi^2(1)=3.30$, $p=.07$). SRV had no effect on first pass regressions out from the target word. SRV reliably affected go past and total time (Go Past: $\beta=.079$, $t=2.64$; $\chi^2(1)=6.60$, $p=.01$; Total: $\beta=.12$, $t=3.51$; $\chi^2(1)=11.04$, $p<.001$). Again, possibility was not reliable in any measure.

Post-target region

Table 3 reports means for untransformed measures on the post-target region. Post-target region models included SRV and possibility as fixed factors, and random intercepts and random slopes for SRV and possibility, for both participants and items. First fixation and gaze duration on the post-target region showed a reliable effect of SRV (First fix: $\beta=.044$, $t=2.26$; $\chi^2(1)=5.06$, $p=.02$; Gaze: $\beta=.064$, $t=2.04$; $\chi^2(1)=3.99$, $p=.046$). First pass regressions out of the post-target region were unaffected by the experimental manipulation. SRV had a marginal effect in go past ($\beta=.062$, $t=1.76$; $\chi^2(1)=2.99$, $p=.084$), but did not reliably affect total time. Possibility did not reliably affect any measure.

Given the lack of any reliable effects for the possibility contrast on the analyzed regions, we looked to see whether there might be any evidence of such an effect on the final region of the sentence, perhaps reflecting wrap-up processes (e.g. Warren, White, & Reichle, 2009). First pass regressions out and go past both showed numerical evidence of disruption consistent with a possibility effect (FPRO final: possible: 28%, impossible/no SRV: 34%, and impossible/SRV: 38%; Go Past final: possible: 819, impossible/no SRV: 888, and impossible/SRV: 1001); however, neither possibility effect was reliable.

Discussion

These results show that impossibility associated with SRVs and impossibility not associated with SRVs differentially affect readers' eye movements. This was evident in the contrast between the lack of effects of possibility and the reliable effects of SRV on go-past in the target region, first fixation durations and gaze durations on the post-target region, and in rereading measures like total time on both the pre-target and target regions. This wide divergence between the impossible/SRV condition and the other two conditions is different from the pattern that was evident in the possibility judgment norming. Given that the large difference in possibility ratings for the possible and impossible/no SRV conditions had little or no effect on reading times in these conditions, the small and statistically unreliable difference in possibility ratings between the two impossible conditions is not likely to have

driven the current effects. The current findings, that comprehenders process impossible sentences with and without SRVs differently, are the best evidence to date that selectional restrictions can dissociate from general event knowledge during language comprehension.

In the current experiment, eye-movement disruption to the impossible/SRV condition first reliably appeared in go past on the target region and on first fixation duration in the post-target region. This is slightly later than the first fixation effects on the target word in Warren and McConnell (2007) and gaze duration effects on the target word in Warren, McConnell, and Rayner (2008). One potential reason for the slightly later effects in the current experiment could be that the previous experiments had more context before the target word, allowing readers to develop stronger models of the unfolding message. However, even though the current effects initially appeared in go past on the target and in first fixation duration on the post-target region, they do not necessarily reflect disruption at only a late stage of processing. Models of eyemovement control in reading include multiple mechanisms by which effects in these measures could reflect differences in lexical or early post-lexical processing at the target word (see Warren, 2011, for discussion). But the fact that total times on the pre-target and target regions were reliably longer in the SRV condition suggests that participants did have more difficulty with late stages of processing in this condition, consistent with previous findings and the intuition that it is very difficult to build a coherent discourse model for sentences with SRVs.

Although there was numerical evidence of disrupted reading in the impossible/no SRV condition on total times in the post-target region and go past and first pass regressions out of the sentence-final region, this condition never reliably diverged from the possible condition. Many previous studies have found disruption in conditions with world knowledge violations, but it is usually less than in conditions with SRVs (e.g. Paczynski & Kuperberg, 2012; Rayner et al., 2004; Warren & McConnell, 2007). The current lack of effect is surprising, but interesting. There are multiple possible reasons for it, any of which would require further experimentation to confirm. One possibility is related to the fact that although the events described in the baseline sentences in the current experiment were possible, many were relatively unlikely. Evidence confirming this relative unlikelihood comes from the fact that the possible condition in the current experiment had a mean possibility rating of .85 (“possible” was coded as 1 and “impossible” as 0) as compared to mean possibilities of .97 for the plausible condition and .74 for the very implausible condition in Warren and McConnell (2007). We designed the study in this way so that the comparison between the baseline and impossible/noSRV conditions would be more likely to reflect event possibility rather than predictability, expectations, or production likelihood, all of which are higher for more likely events and have been shown to affect processing and eye movements in reading (e.g. Ehrlich & Rayner, 1981; Matsuki et al, 2011). This lack of processing difference between the possible and impossible/noSRV conditions could be evidence that possibility status has little influence on the processing of unexpected or somewhat unlikely events. To our knowledge, this possibility has not been tested in the literature and could be an interesting avenue for future research. A second possible explanation is related to the length of the sentences tested. In the current study, the context before the target word consisted of a subject NP, a verb, the determiner *the*, and an

adjective. We intentionally used short simple sentences to minimize the possibility that comprehenders would forget or skim part of the sentence or be confused about who was doing what to whom. However, the amount of context and the time available to build a message-level representation can influence how strongly that representation constrains the processing of a target word (see Kuperberg, 2007 for a discussion). Most, but not all (c.f. Hagoort et al., 2004), of the previous studies investigating SRVs and semantic anomalies cited above had a richer context; for example, many of them included an instrument that was used in the event and the extra words “used” and “to”. Perhaps that longer and richer context led participants to build a richer set of expectations for likely arguments, which led to greater disruption when those expectations were violated. Nailing down the role of context length on anomaly detection could be an interesting topic for future research. Still, what is critical in the current experiment is that comprehenders processed SRVs versus world knowledge possibility violations differently. If event possibility were driving processing disruption in the current items, then these two conditions should have patterned similarly.

What drives this difference in disruption to SRVs versus general world knowledge violations? Although plausibility violation severity influences disruption (e.g. Rayner et al., 2004; Stewart, Pickering, & Sturt, 2004), it seems unlikely that this drove the current effects, because all impossible events should have similarly low plausibility. It could be relevant that diagnosing the impossibility of the impossible/no SRV condition requires considering both the agent and verb of the event, whereas the SRV condition requires only considering the verb. However, there is considerable evidence that agents (or subjects) influence the on-line interpretation of verbs (e.g., Kamide, Altmann, & Heywood, 2003; Hare, Elman, Tabaczynski, & McRae, 2009), which runs counter to the notion that direct object (or patient) processing may be influenced by an agent-independent interpretation of the verb. Given that the current sentences were syntactically simple and their agent and verb were easily identifiable, it seems likely that our participants, like those in the studies cited above, constrained their interpretation of the verb and their expectations for upcoming post-verbal arguments based on the agent they had just processed. A third possible account of the difference in response to SRVs versus world knowledge could be related to likely differences in how frequently the strings *explored/lifted/entertained a nearby backpack* are encountered. Patson and Warren’s (2010) findings weigh against this explanation of the current effects. Patson and Warren found eyemovement disruption latency was similar for sentences like *Bryan used a bottle to fight off the hungry infant...* and *Bryan used a trough to feed the hungry infant...* compared to *Bryan used a bottle to feed the hungry infant....* In their items, the verb plus patient combination was more natural and thus likely more frequent in one implausible condition than the other (i.e. *feed the hungry infant* vs. *fight off the hungry infant*). However, this difference did not affect the timing of the initial disruption readers experienced.

One intriguing account of this pattern of results is that SRVs are more likely to be detected because they are cued by mismatches of coarse-grained semantic features (Warren & McConnell, 2007), and coarser-grained semantic features are available earlier and/or more likely to be used in semantic processing than finer-grained features (Sanford & Garrod, 2005). Consider the grain size of the semantic mismatches in the impossible/no SRV and

SRV conditions. To determine that hamsters can't lift backpacks in the impossible/no SRV condition, one must access information about the usual weight and size of backpacks and strength of hamsters. However, to determine that backpacks can't be entertained, it is only necessary to recall that they are inanimate objects. As for the fact that disruption in the SRV condition is sustained, one possible explanation is that violations of coarser-grained semantic features lead to more difficulty building coherent discourse models (cf. Warren & McConnell, 2007). Going back to our example, it seems easier to adjust assumptions about the size, weight, and strength of a particular backpack and hamster than to assume sentence on the part of a backpack. Indeed, Nieuwland and van Berkum (2006) showed that coercing an inanimate object into being understood as an animate actor required multiple exposures.

This work (as well as the account suggested above) highlights the question of what selectional restrictions are. The original conception of selectional restrictions – as a stipulated set of semantic features that are stored as part of the modular lexical entry for a verb – is likely untenable, on both theoretical (Jackendoff, 2002) and empirical grounds (Duffy, Rayner & Morris, 1986; Nieuwland & van Berkum, 2006). However, Paczynski and Kuperberg (2012) and Kuperberg (2013) provide a conceptualization of event knowledge that could support a different account of selectional restrictions. They argue for the existence of event abstractions at coarse-grained levels like Agent <animate>; Action; Patient <inanimate>, as well as at finer-grained levels like Experiencer <people>; State <awe>; Stimulus <view>; Place <peak of mountain>. Selectional restrictions could naturally fall out of event abstractions that were a blend of these two levels – fine-grained with respect to the action or state and coarse-grained with respect to the participants (e.g. Agent <animate>; Action <scatter>; Patient <particulate>). These abstractions would exist alongside and ultimately be derived from exemplar-type representations of events in memory (McRae & Matsuki, 2009), much as prototype representations may be derived from accumulated experience with category exemplars (e.g., Medin, Altom & Murphy, 1984; cf. Dowty, 1991). This conceptualization of selectional restrictions as rooted in abstractions computed over world knowledge is an improvement over older modular conceptualizations in that it both explains their source and doesn't restrict them to a circumscribed set of semantic features that somehow differ from all others. Under this account, as long as an action or state requires a semantic property of its participants, that property would be a semantic restriction.

The current findings suggest that disruption associated with reading about impossible events is not determined by fine-grained world knowledge about event possibility. Coarse-grained abstractions over event knowledge may play a role in comprehension.

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Appendix A

Experimental items. The first verb was the baseline condition, the second the impossible/no SRV condition, and the third the impossible/SRV condition.

1. Corey's hamster explored/lifted/entertained a nearby backpack and filled it with sawdust.
2. Carrie's parakeet pecked/transported/distracted some dirty books piled on the floor.
3. John's pet mouse inspected/stole/amused the closest broom before running away.
4. Jill's dog monitored/retrieved/comforted her old truck from the parking lot.
5. Jake's gerbil chewed/moved/annoyed the nearest watermelon after escaping from its cage.
6. The sparrow scratched/carried/frightened the tall crate and started to tweet loudly.
7. Susan's black cat sniffed/stole/befriended a new microwave before stalking away.

8. Jennifer's pet rat occupied/moved/delighted the larger bookshelf and made itself a nest.
9. The energetic kitten ignored/took/exhausted the newest picture of the smiling couple.
10. The kitchen mice overran/collected/scared the nearest dishes and left droppings everywhere.
11. Elizabeth's cat inspired/examined/soothed a new theory because it was so energetic.
12. The bunny rabbit occupied/knocked over/distracted the nearest armchair and wriggled its nose.
13. The teddybear hamster avoided/dropped/distracted the old cinderblock on the floor.
14. The small dog guarded/stole/drank the black television and growled ferociously.
15. The argument inspired/delivered/angered a scholarly lecture about Beethoven.
16. The heated debate involved/started/endured a long scarf and some gloves.
17. The six month old baby touched/lifted/surprised the nearest canoe before giggling happily.
18. Phil's puppy licked/fetched/impressed the big lawnmower in the garage.
19. The go-kart inspired/made/bumped a reckless promise to never drive again.
20. Morgan's dog buried/filled/reassured the old waterbottle and went to sleep.
21. The mouse climbed/dropped/startled the small boulder in the field.
22. The homing pigeon examined/delivered/angered the red brick and started pecking violently.
23. The skunk sprayed/maneuvered/intimidated the large bulldozer before going back to its nest.
24. The colorful parrot climbed/carried/soothed a large barbell while squawking loudly.
25. The tall giraffe nibbled/walked/startled the long tightrope strung in the rafters.
26. The red-tailed hawk pecked/captured/surprised the colorful picture and flapped its wings.
27. The argument relied on/weakened/angered the small screwdriver that might have been lost.
28. The goldfish nibbled/caught/startled the silver lunchbox that Sam dropped.
29. The tiny fish watched/swallowed/annoyed the brown rowboat floating in the water.
30. Suzie's cat watched/cleaned/alerted the dirty automobile parked in front of the house.

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Table 1

Mean reading measures on the pre-target region in milliseconds.

	First Fix	Gaze	Go-Past	% Reg out	Total time
Possible	228	330	365	8	396
Impossible/no SRV	225	327	369	8	424
Impossible/SRV	232	344	406	12	501

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Table 2

Mean reading measures on the target word in milliseconds.

	First Fix	Gaze	Go-Past	% Reg out	Total time
Possible	245	302	350	11	365
Impossible/no SRV	240	300	348	12	368
Impossible/SRV	250	315	379	14	412

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Table 3

Mean reading measures on the post-target region in milliseconds.

	First Fix	Gaze	Go-Past	% Reg out	Total time
Possible	236	312	371	11	368
Impossible/no SRV	235	315	369	12	401
Impossible/SRV	247	332	395	14	427