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Implicit prosody pulls its weight: Recovery from garden path sentences

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Abstract

Classic reduced relative clause garden path sentences (e.g., *The horse raced past the barn fell*) are notoriously difficult to comprehend, even after repeated exposure [1, 2]. We present a silent eye tracking experiment showing that increasing the weight of the matrix verb phrase with a particle or an adverbial facilitates recovery from misanalysis, as in *The horse raced past the barn fell (down / suddenly)*, but does not protect the processor from the incorrect parse, in which *raced* is erroneously understood as the main verb rather than a verb within a relative clause. Following Fodor's Implicit Prosody Hypothesis [3], we suggest that additional weight after the main verb (*fell*) reduces the penalty for garden path by signaling the prosodic boundary appropriate for a full relative clause [4, 5, 6]. In addition, there were few differences between short but highly predictable particles (*down*) and long but less predictable adverbials (*suddenly*), where predictability was determined by a separate offline completion study. The results highlight the essential role that implicit prosodic constituency plays in garden path recovery, in that it provides structurally relevant cues identifying the source of misanalysis [7, 8].

Index Terms: implicit prosody, reading, garden path recovery, eye movements

1. Introduction

An important direction in language processing research pursues the idea that readers assign a prosodic representation to text during silent reading [3, 9, 10]. Given the close, though not exact, correspondence between prosodic and syntactic structure [11, 12, 13], decisions that govern prosodic assignment are likewise expected to impact parsing routines and recovery processes, as in Fodor's Implicit Prosody Hypothesis:

(1) The Implicit Prosody Hypothesis (IPH): In silent reading, a default prosodic contour is projected onto the stimulus, and it may influence syntactic ambiguity resolution. Other things being equal, the parser favors the syntactic analysis associated with the most natural (default) prosodic contour for the construction. [3]

Thus, we assume that when readers activate an inner voice, textual components related to intonation, prosodic phrasing, rhythm and prominence play an important role in how sentences are processed during real-time comprehension (see [14] for review). Perhaps the most well explored of these components is prosodic phrasing, in which a set of words is grouped into natural prosodic units. Its importance to online processing has been clearly established for both spoken [15, 16] and written [17, 18] language comprehension. In addition to orthographic indicators of prosodic phrasing, like commas [10, 17, 19, 20], readers appear to group words into prosodic phrases using prosodic weight, e.g., length, groupings which potentially carry syntactic ramifications [5, 21]. An important general question is the extent to which such groupings influence processing temporarily ambiguous sentences. Cases like the ambiguous example (2) suggest that length does indeed affect interpretations related to boundary position (#). Whereas the adjective *ugly* modifies the within-phrase noun *professor* in (2a), it seems more apt to modify *daughter* in (2b), as *horribly* forces *professor* to form a prosodic phrase with *daughter* [18, 21].

(2) a. (The ugly professor's) # (daughter)

b. (The horribly ugly) # (professor's daughter)

In this study, we explore the role of implicit phrasing in recovering from misanalyses in classic reduced relative clause garden path sentences [1, 2]. In example (3), the verb of the reduced relative clause (*raced*) is initially understood as the matrix verb in (3a), a commitment which must be revised when the parser receives the true matrix verb (*fell*) in (3b). Notably, the syntactic revision is accompanied by a prosodic one, in which a large juncture appears between *barn* and *fell*.

(3) a. The horse raced past the barn ... (*raced* main verb)

b. The horse raced past the barn fell ... (*fell* main verb)

We compared how the costs of processing a temporarily ambiguous reduced relative clause over an unambiguous unreduced relative clause (*The horse that was raced ...*) would be affected by the weight of the second, matrix, verb phrase. As increasing constituency length increases the likelihood of a prosodic break [22, 23, 24, 25], we hypothesized that adding a particle (*down*) or an adverb (*suddenly*) after the matrix verb (*fell*) would entice the processor into positing a prosodic boundary (#) before the matrix verb (4a). A boundary in this position would be consistent with the boundaries of the target prosodic representation of an unreduced relative clause (4b).

(4) a. The horse (#) raced past the barn # fell down

b. The horse (#) that was raced past the barn # fell down

Having to make revisions to the prosodic representation in addition to the syntactic representation is known to make recovery from garden path sentences more difficult [9]. Conversely, we predicted that indicators of the ultimately correct prosodic phrasing would facilitate the revision process.

In addition, we manipulated whether the additional weight was provided in the form of short and highly predictable verbal particles (*over*) or long and less predictable adverbs (*suddenly*). On the one hand, a highly expected continuation might facilitate garden path recovery simply by helping the parser recognize the appropriate structure, in addition to the additional weight. On the other, a heavier continuation might provide a better cue for the boundary, even if it is not expected. We tested our predictions in a silent eye tracking study, described below.

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2. Eye tracking study

2.1. Participants

Forty eight native English-speaking undergraduates were recruited from the UCLA Psychology Subject Pool, and were compensated with course credit. All participants had normal or corrected-to-normal vision. Five participants were excluded for blinking in the go past reading of the critical region on over 3 instances of any one condition or more than a third of total trials. Five additional participants were run in their place under the same counterbalancing list. The experiment typically lasted 30 to 45 minutes.

2.2. Materials

Twenty four sextets were created for 2×3 design, crossing *Relative Clause Type* (RC Type: Reduced, Unreduced) and *Continuation* (None, Particle, Adverb) as shown in (5). The pipe symbol '|' indicates how the sentence was divided into regions for analysis after the experiment. Region 3 contains the main verb and, in some conditions, a continuation.

(5) $|_1$ The exhausted hiker $|_2$ (who was) cautioned about the trail...

a. *None:* $|_3$ sat ...

b. *Particle:* $|_3$ sat down ...

c. *Adverb:* $|_3$ sat quietly ...

$|_4$ by the river $|_5$ enjoying the scenery.

Materials were first normed in two offline experiments, both of which were conducted over the Internet. Participants were recruited from Amazon's Mechanical Turk and adminstered the experiments through Ibex Farm (`http://spellout.net/ibexfarm/`). Participants self-reported as native speakers of English and passed a series of difficult comprehension questions and catch items.

The first norming study was a sentence completion task ($N = 36$) conducted on fragments like *The exhausted hiker (who was) cautioned about the trail sat ...* Participants often supplied the particle (M = 37%; range 14%–75%) as the first word immediately following the matrix verb. Adverbs were rarely provided ($M < 1\%$). No differences in frequency of occurrence were observed for RC Type. The second norming study was a naturalness rating study ($N = 30$) conducted on a 7-point Likert scale (7 = "Totally natural"). Participants rated reduced RCs (M = 3.06, SE = 0.08) as less natural than unreduced RCs (M = 4.52, SE = 0.09), according to a sum-coded linear mixed effects regression model, t = -14.33. Although neither type of continuation improved ratings significantly, there was a trend for particles to differentially improve ratings when following a reduced RC, t = 1.56.

2.3. Procedure

Participants were instructed to read naturally for comprehension and at their own pace, and their eye movements were recorded with an SR Research Eye Link 1000. Viewing was binocular, but only the right eye was recorded. Text was presented on a single line, and drift correct was performed between each trial. Materials were presented in individually randomized and counterbalanced order, randomly interspersed with 48 items from unrelated experiments, and 16 non-experimental filler sentences. Participants were presented with comprehension questions presented after approximately half of the items, each answering at an accuracy rate of over 80%.

3. Results

The data were automatically cleaned of blinks, long (over 1200ms), and short (under 80ms) fixations, using RoboDoc (written by Adrian Staub and Chuck Clifton). Standard eye movement measures were collected [26]. Data analysis was conducted in R. We used a linear mixed effects regression model from the `lme4` package [27] with sum-coded fixed effect variables for *first fixation duration* (the time of the very first fixation into a region), *first pass time* (the sum of all fixation durations upon entering a region before exiting to the left or the right), *go past time* (the time spent in a region before exiting to the right), and *total times* (all time spent in a region). For such models, we adopt the convention that t-values above ± 2 indicates significance. A factor encoding region length as measured by the total number of characters was added to models for Regions 2 and 3. As *second pass time* (the time spent in a region after exiting it to the right) conventionally includes zero times, indicating a failure to fixate on a region, this measure usually violated a sphericity assumption associated with the models above. Second pass times were analyzed in split by-subject F_1 and by-item F_2 ANOVAs, using Huynh-Feldt sphericity corrections in the `ez` package [28]. We first present main effects observed for reduced RC garden paths and increased length of the particle and adverb post-verbal continuations. We then report the central interaction of interest: how post-verbal particles and adverbs impacted reading in different types of relative clause.

3.1. Reduced relative clause garden path effects

As would be expected from legions of previous studies on garden path sentences, there was an immediate and sustained penalty for reduced RCs over unreduced variants. On the matrix verb phrase region, the penalty manifested on every continuous measure examined, Figure 1, as well as in increased regressions out of the region. The penalty for reduced RCs appeared on nearly all regions for every measure, but a complete description is omitted for space.

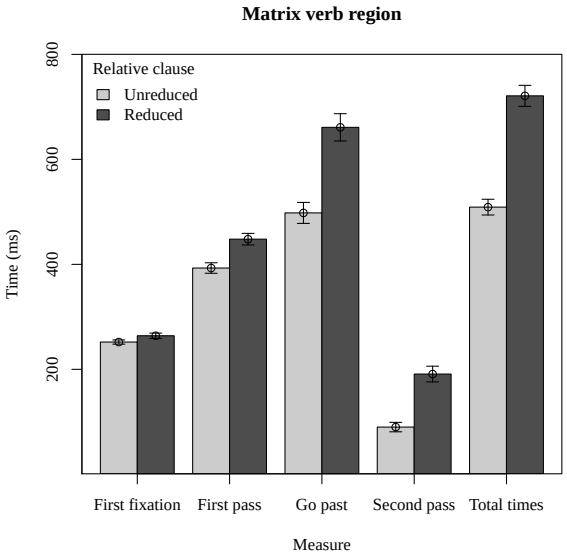

Figure 1: Reduced relative clause penalty on matrix verb region. All differences were significant.

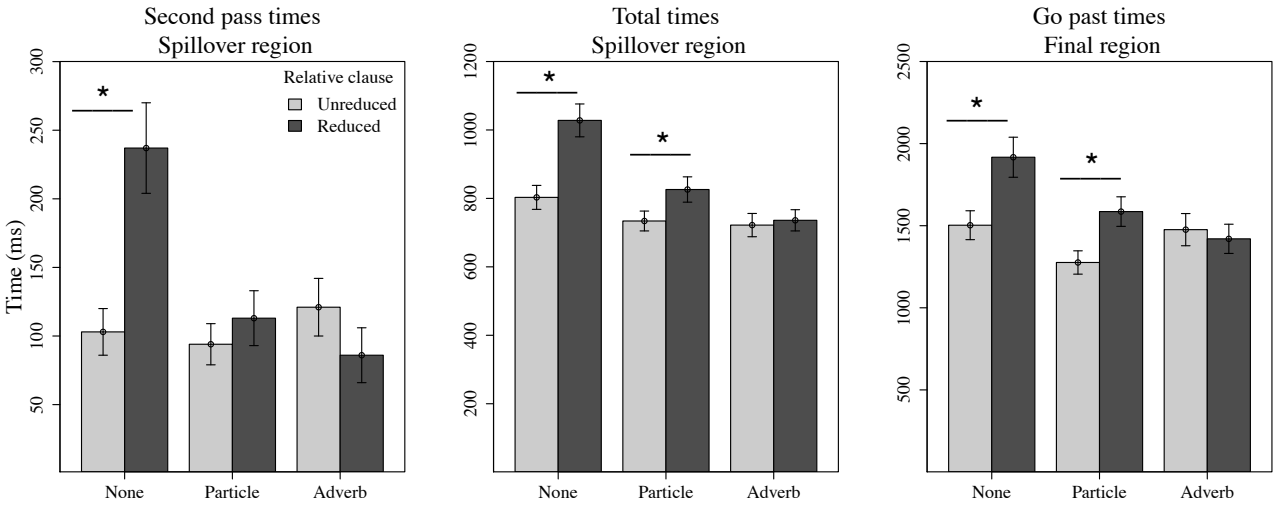

Figure 2: Interactions between Relative Clause Type and Continuation. Second pass and total times on the spillover region, and go past times on the sentence final region. The asterisk '*' signifies significance in paired by-subject and by-item *t*-tests at the $\alpha = 0.05$ criterion.

3.2. Continuation effects

In general, readers spend more time in longer regions [26]. A main effect of longer reading times for conditions with a post-verbal continuation was observed in multiple measures, including go past and total times, on the critical verb region. These effects are expected and largely orthogonal to the experimental question.

However, we also found that adverbs and particles did not elicit the same length effect. For instance, in a model where length was included as a covariate, adverbs elicited marginally longer reading times in first pass durations (M = 552ms, SE = 14) than the simple verb baseline (M = 293ms, SE = 8), t = 1.91, although particles (M = 417ms, SE = 11) did not. Adverbs also elicited more regressions out of the matrix verb region (M = 24%, SE = 2) than the plain verb baseline (M = 17%, SE = 2), z = 2.60, $p < 0.01$, whereas particles did not (M = 17%, SE = 2). However, the effect was short lived, as adverbs elicited significantly fewer regressions out of the spillover region (M = 12%, SE = 2) than plain verb counterparts (M = 25%, SE = 2), z = -3.88, $p < 0.001$, which again did not differ from particles (M = 20%, SE = 2). The effect may be due to the fact that adverbs were longer than particles in general, or to an increased integration cost for more semantically contentful items.

3.3. Reduction of garden path effect

The primary effect of interest was the interaction between RC Type and Continuation. As predicted, the garden path effect was reduced or eliminated for items with an adverb or particle immediately following the verb. The reduction manifested in the post-verbal spillover region in re-reading measures.

Particles (19ms difference) and adverbs (35ms difference) elicited differentially shorter second pass times in the spillover region in reduced RC conditions than a plain verb alone (134ms difference), in by-subject, $F_1(2, 46)$ = 6.81, $p < 0.05$, and by-item, $F_2(2, 22)$ = 8.77, $p < 0.001$, ANOVAs correcting for sphericity. Differences were confirmed in t-tests on planned *a priori* comparisons. Whereas reduced RCs elicited longer second pass times for matrix verbs without a continuation adding prosodic weight, $t_1(47)$ = 4.73, $p < 0.001$, $t_2(23)$ = 4.15, $p < 0.001$, the effect of RC Type was eliminated for both particles and adverbs; see the first panel in Figure 2.

A similar pattern manifested in total times on the spillover region. There was again a significant interaction in by-subject, $F_1(2, 46)$ = 5.28, $p < 0.001$, and by-item, $F_2(2, 22)$ = 6.89, $p < 0.001$, ANOVAs. However, *post-hoc* t-tests revealed a difference between continuation types in this region. While an adverb eliminated the cost of a reduced RC in the spill over region, t's < 1, a particle did not, $t_1(47)$ = -2.09, $p < 0.05$, $t_2(23)$ = -2.28, $p < 0.05$; see the middle panel in Figure 2.

In the sentence final region, there was an interaction between RC Type and Continuation in by-subject, $F_1(2, 46)$ = 3.31, $p < 0.05$, and by-item, $F_2(2, 22)$ = 4.95, $p < 0.05$, ANOVAs corrected for sphericity. As before, the effect appeared to be primarily due to the adverb condition, in which there were no differences between RC Type levels, t's < 1. Reduced RCs were still costly in both the plain verb, $t_1(47)$ = 3.53, $p < 0.001$, $t_2(23)$ = 3.23, $p < 0.01$, and the particle, $t_1(47)$ = 2.29, $p < 0.05$, $t_2(23)$ = 3.21, $p < 0.01$, conditions; see the third panel in Figure 2 for illustration.

4. Pilot production study

Our interpretation crucially depends on the assumption that the relative clause is offset by prosodic breaks in production, as in (4) above. We probed this assumption in a *post hoc* production study. Six UCLA undergraduates were recorded producing 12 full RC and 12 reduced RC sentences, i.e., 24 critical tokens per subject, that were sampled from the experimental items. Four tokens from each of the six conditions were presented in one of two counterbalanced and randomized lists, interspersed with fillers with unrelated structures.

First, participants were presented with the target sentence on a computer monitor to read silently. After they finished reading the sentence, they read the sentence aloud. One third of the sentences were followed by a question to test their comprehension. Accuracy was high, at a rate of 95% across participants,

Continuation	RC Type	Post NP	Post RC	Post VP
None	**Total**	75%	96%	33%
	Unreduced	83%	100%	8%
	Reduced	67%	92%	58%
Particle	**Total**	88%	100%	55%
	Unreduced	83%	100%	42%
	Reduced	92%	100%	67%
Adverb	**Total**	92%	100%	71%
	Unreduced	92%	100%	75%
	Reduced	92%	100%	67%

Table 1: Prosodic breaks of 3- or higher by condition in critical sentences.

with no participant scoring lower than 80%.

The prosodic breaks of the recordings were then labeled using the MAE_ToBI (Mainstream American English Tones and Break Indices) annotation convention [29]. Although only half of the critical sentences (12 of 24) have been labeled so far, each condition is represented equally across each participant. For present purposes, we define a "prosodic break" as either an Intermediate phrase boundary (break index of 3 or 3-) or an Intonational phrase boundary (break index of 4 or 4-). We found seven ambiguous prosodic junctures smaller than 3- but larger than 1 (word level). These cases were excluded from analysis.

In almost every case, participants placed a prosodic break at Region 3, immediately following the RC prior to the main verb (*sat*). In the vast majority of cases, participants also placed a prosodic break at Region 2, after the subject noun, preceding the start of the RC. In all, the results of the production data suggest that participants did indeed mark RC boundaries with prosodic breaks, as expected.

In addition, the rate at which subjects placed a boundary after the main verb varied considerably by condition. When the verb lacked a continuation, i.e., the None condition, the verb region was marked with a boundary after the verb in only 1 of the 12 trials (8%) following an unreduced RC. Participants appeared to delay marking a boundary in these cases until Region 4 in 92% of the trials. In contrast, subjects placed a boundary after the verb in 58% of the reduced RC conditions, and were less likely (67%) to place a boundary at Region 4. Further, participants placed boundaries after a main verb with a particle (55%) less often than after a main verb with an adverb (71%).

5. Discussion

Although neither adverbs nor particles prevented the processor from going down the garden path, their presence reduced re-reading times in regions following the point of disambiguation, i.e., the matrix verb (*sat*). We suggest that the additional prosodic weight afforded by verbal particles and adverbs provides a useful cue to the proper prosodic constituency of the target parse, in line with previous research [4, 5, 6, 18, 30]. Consequently, the results contribute to the already broad support for Fodor's Implicit Prosody Hypothesis, in which default prosodic phrasing, among other prosodic factors, influences syntactic ambiguity resolution. For example, ERP research on Korean observed that increasing the length of sentence-initial subjects reduced the garden path penalty on disambiguating regions downstream [18]. The authors propose that the processor posited a prosodic boundary after longer subjects, which in turn factilitated the appropriate analysis. Similarly, we find that increasing prosodic weight after a matrix verb reduced the garden path effect, without fully circumventing it. Furthermore, the fact that increased predictability did not additionally assist the processor highlights the essential role of implicit prosodic constituency in garden path recovery.

In some measures, however, adverbs reduced the garden path penalty more than particles did. Several possibilities might account for the difference, all of which require further support to be evaluated. A prosodic possibility that is directly compatible with our basic hypothesis would attribute the greater impact of adverbs on recovery to their increased weight; the adverbs used here tended to be three or four syllables long, whereas particles were typically only one. Such a view could be given additional support if adverbs tend to attract greater prominence or a stronger boundary than verbal particles in production. Impressionistically, results from our pilot production study support this interpretation, as post-verbal adverbs were almost always accented, whereas particles almost never were.

Further, the length of a continuation likely affected whether the post-verbal item was accessible in parafoveal preview, a position in the visual field just outside the point of central, foveal vision [31]. Short, frequent, and highly predictable words like *the*, *a* and perhaps the particles used here, are readily identified within preview [32]. To speculate, items that are completely identifiable in preview might not add as much weight as fully independent lexical items in silent reading.

Another possibility is an interpretive one, and relies on the assumption that the adverbs were more semantically contentful than the particles were. The adverbs in the experiment were selected to modify the event described by the verb, and to therefore specify the manner in which the event unfolded. In contrast, particles in particle verb constructions might contribute little to the event representation beyond the verb itself. Intuitively, the difference between *sat* and *sat down* is very subtle, though such particles may provide additional specification of a path or completeness of a subevent [33]. The fact that semantically heavier items continued to reduce the garden path penalty might further indicate that prosodic phrasing is also sensitive to semantic weight [34]. This explanation raises a possible interaction between prosodic and semantic heaviness, broadly construed: while length is surely important in creating prosodic boundaries in silent reading, the likelihood of positing an implicit boundary might be increased by semantically rich items.

A final, purely syntactic, possibility relates to the argument structure configurations that are made possible by the different continuations. For example, a few of our particle verbs, like *toppled over*, have both an intransitive (the intended argument structure) and a somewhat awkward transitive use (e.g., *?John toppled over the vase*), whereas the verb-adverb sequence prohibits the latter case (e.g., **John toppled quickly the vase*). The adverb continuation therefore removes the possibility that an object follows the verb. Adverbs may have thus provided a stronger cue that the VP had terminated, thereby prompting the processor to initiate repair at an earlier point in the string, a view consistent with the increased rate of prosodic breaks after adverbs in the production study. All of these possibilities of course remain speculative without further evidence.

The overall results are consistent with the hypothesis that additional prosodic weight facilitates recovery from reduced relative clause garden path sentences. We attribute the general reduction of a garden path penalty to the implicit prosody imposed on text during silent reading, though the locus of the differences between weight-bearing elements remains a matter to be resolved in future studies.

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8. Appendix

Sample items for the experiment. Only the unreduced RC conditions are shown, as the reduced variant was formed by removing the complementizer (*who, that*) and the auxiliary that immediately followed it.

1. The persistent flirt | who was paid a compliment | toppled (over / suddenly) | after a long night | at the local bar.
2. The boutique book store | that was sold the first edition | closed (down / surprisingly) | after years of business | at that location.
3. The expensive car | that was sped around the track | broke (down / completely) | only a few minutes | after the race began.
4. The clumsy kid | who was passed the ball | fell (down / wearily) | onto his knees | at the three-point line.
5. The exhausted hiker | who was cautioned about the trail | sat (down / quietly) | by the river | enjoying the scenery.
6. The furious judge | who was denied the motion | walked (away / briskly) | toward his car | parked outside the courthouse.