Prominence in Relative Clause Attachment: Evidence from Prosodic Priming

Sun-Ah Jun and Jason Bishop

Abstract This chapter presents two experiments utilizing prosodic adaptations of the structural priming paradigm. In each experiment, the goal was to explore the relation between the location of a prosodic boundary and the preferred parsing of a relative clause (RC) with ambiguous attachment to a preceding head noun. In Experiment 1, using read materials, ambiguous target sentences were preceded by prime sentences with RCs of different length: long, medium, and short. RC length was hypothesized to influence the location of an implicit prosodic boundary in the primes. However, no effect for this RC-length manipulation was found. In Experiment 2, the location of a boundary was manipulated in overt (spoken) prime sentences. For these auditorily-presented primes, the location of a prosodic boundary was found to influence attachment preference for targets. Interestingly, the effect was in the opposite direction as predicted: In the configuration NP1 NP2 RC, a boundary after NP2 resulted in *more* NP2 attachments. We propose that in the experimental materials, which contained equivalent accents on the two noun phrases (NPs), the boundary after NP2 leads to the accent on NP2 being interpreted as the nuclear pitch accent. Consequently, that accent was perceived as being more prominent than the accent on NP1, thus attracting RC attachment. The results suggest a close relationship between prosodic phrasing and prosodic prominence in English, and demonstrate a role for both in sentence processing.

Keywords Explicit prosody · Prosodic priming · Working memory · Autistic traits · Autism Spectrum Quotient (AQ) · Head prominence · Edge prominence

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1 Introduction: The Implicit Prosody Hypotheses and Sentence Processing

In a sentence such as (1), it is ambiguous whether the relative clause (RC) modifies NP1 *the servant* (high attachment) or NP2 *the actress* (low attachment):

(1) *Someone shot the servant of the actress who was on the balcony.*

Although attachment possibilities are, strictly speaking, ambiguous in such cases, it is now well known that readers show preferences towards either high or low attachment in silent reading tasks. Furthermore, the direction of this preference is in part predictable based on native language, although the divisions defy reasonable typological distinctions. For example, while native English speakers prefer low attachment (Frazier and Clifton 1996; Ehrlich et al. 1999), Dutch and German speakers favor high attachment (Hemforth et al. 1998; Brysbaert and Mitchell 1996); and while Spanish speakers prefer high attachment (Cuetos and Mitchell 1988; Carreiras and Clifton 1993), Romanian speakers prefer low attachment (Ehrlich et al. 1999). It is also known that attachment preference can vary within a language as a function of experimental task (e.g., Augurzky 2006; Sekerina et al. 2004), and especially as a function of phonological weight (which we describe in more detail below).

In the present study, we are interested in a particular and very influential theory about the source of these preferences, namely the Implicit Prosody Hypotheses (IPH) proposed by Fodor (1998, 2002). While acknowledging that some individuals are claimed to lack subvocal prosody in reading, Fodor (2002) describes the IPH as in (2), which is accompanied by the two assumptions in (3):

(2) **The IPH (Implicit Prosody Hypothesis):**
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 that sentence.

(3) **Working Assumptions**:
a. The comprehender will be more likely to postulate a large syntactic boundary at the location of a large prosodic boundary.
b. The implicit prosody projected onto the sentence in reading will be identical to the explicit (i.e., overtly spoken) prosody for that sentence in a comparable context.

Of particular interest in the present study is the assumption in (3b), which pertains to the accessibility of implicit prosody to empirical investigation. As we discuss below, recent studies have produced findings that are problematic for this assumption, leading to the question of how implicit prosody can be studied, and therefore also how the IPH can be tested. In the rest of this chapter, we pursue this issue as follows. In Sect. 2, we discuss recent studies of implicit prosody and the problems associated with equating it to explicit prosody. Then, in Sects. 3 and 4, we present two novel experiments, using adapted versions of the structural priming paradigm, which are intended to circumvent these problems. Finally, in Sect. 5, we discuss our results and their implications for the relation between prosody and sentence processing.

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2 Testing the Implicit Prosody Hypothesis

2.1 Support

A useful starting point for assessing the claims of the IPH is to consider one of its most compelling applications: the phenomenon of length effects on attachment bias in silent reading. An early observation in the study of attachment preference was that simple constituent length was positively correlated with a preference for high attachment (e.g., Fernández and Bradley 1999; Quinn et al. 2000; Lovric et al. 2001; Fernández 2003; Jun 2003a). In speech it is understood that, other things being equal, the edges of longer constituents tend to require more phrase boundaries (e.g., Selkirk 2000; Nespor and Vogel 1986; Jun 1996, 2003a, b), and so length effects on attachment have a straightforwardly prosodic explanation. According to the IPH, therefore, it needs only to be assumed that this prosodic "chunking" of a long RC occurs implicitly during reading, and, according to (3a), a resulting implicit boundary before an RC prompts high attachment of that RC.

Further evidence that the IPH is a necessary component to an explanation of length effects comes from the findings of Swets et al. (2007). In their study, with Dutch and English native speakers, subjects were asked to read sentences such as (1), above, where the RC either occurred or did not occur on the same printed line as the rest of the sentence. Although English (unlike Dutch) is a low-attachment language, the authors found that readers of both languages preferred high attachment when the RC was read on a separate line. Additionally, Swets and colleagues found that a preference for high attachment was present in individuals with lower working memory capacity (indicated by a latent variable based on measures of both spatial and verbal working memory). The IPH is able to handle both of these findings neatly and in the same way: The insertion of an implicit prosodic boundary drives attachment as per (3a). In the first case, it need only be assumed that the implicit prosodic juncture is cued by the visual juncture; in the second case (and as pointed out by Swets and colleagues), it can be assumed that individuals with lower working memory are more likely to insert an implicit boundary before the RC so that the sentence is chunked into smaller, more manageable processing units. This boundary, in turn, encourages closure at that location (i.e., high attachment).

2.2 Problems

Patterns of attachment preference related to length, which occur within language, thus seem to require reference to implicit prosody, and in this way motivate the IPH's explanation for the cross-linguistic asymmetries as well. According to the IPH (Fodor 2002, p. 123), languages in which native speakers exhibit an overall high attachment bias do so because they are, by default, inserting an implicit boundary between the RC and the adjacent head noun, but not between the two head nouns. In languages where speakers exhibit an overall low-attachment bias, however, it is

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assumed that this default implicit boundary occurs instead between the two head nouns and not between the RC and the adjacent head noun (thus grouping the lower NP together with the RC). According to (3b), we therefore expect to observe this very same cross-linguistic asymmetry in the placement of explicit boundaries in speakers' productions of the same sentences. In fact, production studies have been carried out for both Japanese and Korean languages with the syntactic configuration of RC preceding the head nouns (Jun and Koike 2003 for Japanese; Jun and Kim 2004; Jun 2007 for Korean). Because these languages are both high-attachment languages, it is assumed they are assigned the implicit prosodic structure (RC)//(NP's NP), and in both cases, the strongest prosodic boundaries were indeed found to be directly after the RC, supporting the IPH.

In more recent work, however, the analogous question has been asked for English, which, as described above, is a language with a low-attachment bias. In English, where the head nouns are ordered as NP1 and NP2 and precede the RC, the IPH predicts the largest implicit—and under assumption (3a) also explicit—prosodic boundary to occur between the two nouns (NP1)//(NP2 RC) in the same sort of out-of-the-blue readings. However, this was found not to be the case by Bergmann and Ito (2007), Bergmann et al. (2008), or Jun (2010; see also Jun and Shilman 2008), the latter of which was a large-scale production study. Instead, these authors all report native English speakers to place the largest prosodic boundary in the sentence directly before RC—just as the speakers of Japanese and Korean did. Furthermore, even when sentences contained grammatical and sematic information favoring low attachment (and speakers were given a chance to read the sentence carefully before reading it aloud), this late-occurring boundary was nonetheless the preferred pronunciation. Thus, although initially promising, production evidence now suggests that speakers, in out-of-the-blue readings, prefer a large prosodic break between the RC and the head noun regardless of attachment differences—and so fails to support the IPH's explanation for cross-linguistic differences in attachment biases.

2.3 Accessing Implicit Prosody

The length effects discussed above make a strong case for the existence of implicit prosody, and its influence on sentence processing. The production findings just described, however, indicate that, if implicit prosody functions as Fodor and colleagues claimed, the use of explicit prosody may not be a reliable way to investigate it. Though unfortunate from the perspective of methodological convenience (and in conflict with Fodor's assumption 3b), this does not necessarily constitute strong evidence against the basic insight of the IPH. Indeed, in discussion of her findings for English, Jun (2010) reviews evidence showing that, if the goal is to obtain speech that maximally encodes syntactic or semantic structure, the standard method of eliciting prosody from reading aloud may be inadequate. Instead, speakers may produce only a very basic "surface" prosody, in which fluency is the speaker's primary goal. Such "performance prosody" may differ significantly from prosody

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produced in spontaneous speech, intentionally disambiguating speech, or, most pertinent here, the internal speech generated during silent reading. While further production research is needed to confirm whether a (NP1 NP2)//(RC) (or (RC)//(NP2 NP1)) phrasing is in fact the universally preferred out-of-the-blue production, there is sufficient reason to doubt that reading aloud is a well-suited way to determine the form of implicit prosody.

However, if the "surface" prosody obtained in reading aloud is insufficient for investigating "deeper" implicit prosody, how might we then approach this problem? Jun (2010) offers a number of possibilities that involve either encouraging readers to encode structure in their productions, or that utilize online processing methodologies that circumvent the production issue altogether. One of the possibilities that is not mentioned in Jun (2010), but which may be effective, is to instead influence implicit prosody more directly, such as through structural priming, and observe outcomes on sentence comprehension. The structural priming paradigm (e.g., Bock 1986), well known in syntactic processing literature, exploits the tendency of speakers and listeners to "reuse" recently encountered syntactic structures (see Pickering and Ferreira 2008 for a recent review). However, can prosodic structure also be primed?

This matter has been investigated in recent research, but we feel that the evidence is somewhat unclear at this point. Tooley et al. (2013) present a study with native English-speaking subjects who heard sentences such as "The dog that pawed the door needed to be let out." that contained either (a) no boundary, (b) a boundary in a "dispreferred"/marked location before the object, (c) a boundary in a "preferred" location after the object, or (d) a boundary in both locations. In one experiment, subjects were to listen to sentences with one of these prosodic structures, and repeat it back, i.e., to produce the same sentence overtly after listening. When this was the task, subjects tended to repeat the sentence with a boundary in the same location, suggesting there may have been some priming that took place (the authors argue that this is less well explained by simple phonetic repetition than abstract structure priming, and present evidence in support of their interpretation). However, in subsequent experiments in which subjects heard sentences and then reproduced a novel (but similar) one, the prosodic structure was not found to carry over to the novel sentence. This finding was interpreted by the authors as indicating that the abstract representation of prosodic structure can be primed (just as syntactic representations can be primed), but tends to be weaker, not lasting as long as syntactic priming has been found to. Possibly, according to Tooley and colleagues, this is due to the fact that prosody is subject to a larger number of constraints than is generally assumed to be the case for syntax.

As discussed earlier, however, the act of producing sentences from reading can often result in prosody that is more focused on fluency than on the encoding of structure. It is thus possible that the priming effects found by Tooley et al. (2013) were obscured by this fact. The question we wish to ask here is whether priming effects can be observed in implicit prosody, which, in principle, should be less affected by the difficulties involved in eliciting overt productions. In the first experiment presented below, we attempt to exploit the reliable relation between

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boundary placement and constituent length (discussed in Sect. 2.1) to explore whether implicit prosody can prime implicit prosody, and whether we can observe its effects on the parsing of ambiguous RCs. In a second experiment, we attempt a slightly different and more direct approach, using explicit prosody to prime implicit prosody. In both cases, the goal is to examine whether RC attachment in English can be influenced by factors that we can attribute only to the location of a prosodic boundary, and whether the result is as predicted by the IPH.

Another factor we considered is the role played by what are sometimes collectively referred to as "cognitive processing styles." These include the aspects of information processing such as working memory capacity and certain personality traits. As discussed in Sect. 2.1, verbal working memory is known to influence attachment bias specifically, and so there was an obvious motivation for collecting this information about participants in our experiments. A second and less common measure of processing style involve "autistic" traits, which, being less commonly studied, we describe in further detail before proceeding.

Autistic traits are behaviors and patterns of information processing associated with a clinical diagnosis with Autism Spectrum Disorder. However, such traits—for example, non-holistic attentional focus, lack of social engagement, and poor communication skills—are known to occur to varying degrees in the neurotypical population as well. These traits are measured in nonclinical individuals using the Autism Spectrum Quotient (AQ; Baron-Cohen et al. 2001), a nondiagnostic, self-administered questionnaire (requiring agree/disagree responses) that divides autistic traits into five separate dimensions pertaining to *social skills, attention to detail, attention switching abilities, communication skills,* and *imagination*. Studies have shown that the AQ, which is scored such that higher scores indicate more autistic traits, has a high level of cross-cultural validity (Wakabayashi et al. 2006; Hoekstra et al. 2008; Ruta et al. 2011; Sonié et al. 2012), although there may be some variation related to culture on the imagination and attention switching subscales (Freeth et al. 2013).

Of primary relevance to the phenomena of interest here is the communication subscale (henceforth AQ-Comm), which contains items such as "I know how to tell if someone listening to me is getting bored." and "Other people frequently tell me that what I've said is impolite, even though I think it is polite." Intuitively, compared with the other subscales, AQ-Comm items relate most to "Theory of Mind" (Premack and Woodruff 1978), or, roughly, the ability to attribute and understand the thoughts and intention of others. Consistent with this, high AQ-Comm scores (indicating poorer, more autistic-like communication skills) are known to be negatively correlated with the use of pragmatic inference in sentence processing in both online and offline tasks (Nieuwland et al. 2010; Xiang et al. 2013; see also Xiang et al. 2011). Crucial to the present study, AQ-Comm has been shown to predict the online interpretation of prosody by Bishop (2012a; see also Bishop 2013) who found individuals with high AQ-Comm to exhibit weaker sensitivity to prosodic prominence in a cross-modal semantic priming task. In particular, although native English speakers are known to prefer high relative prominence on the object in subject–verb–object (SVO) constructions when semantic focus is narrowly on that object (e.g., Bishop 2012b; Breen et al. 2010; among others), this was not replicated

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for high AQ-Comm individuals, who actually showed the reverse preference. While we lack a detailed understanding of how these individual differences influence prosodic perception and sentence processing, we wished to control for such influences here, since they are highly relevant to our task. Therefore, in both of the experiments we present below, participants completed standard measures of both autistic traits and verbal working memory.

3 Experiment 1: Implicit-to-Implicit Prosodic Priming

As described in Sect. 2.1, the effect of RC length on attachment preference has a straightforwardly prosodic explanation: the longer the RC, the more likely a reader is to insert an implicit prosodic boundary before the RC, in turn increasing the probability of a high-attachment parsing. In Experiment 1, we explore whether reading a prime sentence with a long RC, predicted to be more likely to contain a prosodic boundary before that RC, induces a boundary before the RC in a subsequently presented novel sentence. If implicit prosody can be primed in this way, the IPH predicts that its effects should be observable in the comprehension of the novel sentence. In the present case, the priming of a boundary should result in the increased likelihood of a high-attachment parsing of the RC.

3.1 Methods

Stimuli

Sentences, to be used as primes and targets, were designed for a reading experiment. Sixteen sentences containing RCs of medium (6–7 syllables) length were first selected as targets, and were intended to lack any grammatical (e.g., agreement) or semantic information that would favor high or low attachment. To this end, these targets, such as "Someone shot the servant of the actress that was on the balcony." were based on sentences used in previous studies (Frazier 1990; Frazier and Clifton 1996; Felser et al. 2003; Dussias 2003). The prime sentences, to be presented and read immediately before the target sentences, were based on 15 sentences structurally similar to the targets. These basic sentences were used to create 30 total prime sentences, each of different RC length: short (2–4 syllables), medium (6–7 syllables), and long (9–12 syllables). Each of the 15 basic sentences had two versions, each in a different length condition. The full list of prime and target sentences can be found in Appendix A.

In addition to the experimental target and prime sentences, 24 filler targets and 30 filler primes were also designed. In order to reduce the difficulty of the task, 18 filler targets contained either no RC or an RC with one head noun. The remaining filler targets contained RCs and two head nouns, but of these only three had poten-

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tial attachment ambiguity. The primes designed for filler trials, however, were the same as the primes used on experimental trials, in that they all had an RC with two head nouns and had the same three RC length conditions. Each RC length condition included ten primes, but only four of them had potential ambiguity for RC attachment and the rest had an attachment bias either toward NP1 or NP2.

Procedure

A MATLAB script was used to present participants with the primes, targets, and the question that elicited their attachment decisions about the targets. Participants controlled the presentation of the sentences by reading at their own pace. Once a sentence appeared on the computer screen, the participant was to read the sentence silently, and then push a key, which removed that sentence and brought up the next. For each experimental trial, the MATLAB script selected one of the 18 target sentences and 3 prime sentences, all from the same RC-length condition, and presented them randomly. The decision to present three primes on each trial was made in an attempt to induce stronger priming effects (cf. Tooley et al. 2013). The participant proceeded through these three sentences, then, finally the target, in the manner described above. Following the participant's key press after the target sentence, however, a question rather than a new sentence appeared. That question appeared below the target, and asked the subject the standard RC-attachment decision, presenting the two possible NPs as the options “A” and “B.” Whether the high-attachment response (i.e., whether the first NP) appeared on the left as “A” or on the right as “B” was counterbalanced. The participant's response was then collected and the next trial began.

Filler trials proceeded in a similar manner, with the following exceptions. First, as described above, the filler targets did not always contain RCs. Second, participants were, at random, required to answer a question about filler primes; this was done to prevent participants from knowing exactly which sentence in a trial (i.e., every fourth sentence presented to them on test trials) would be the one requiring an attachment decision. Participants carried on through all experimental and filler trials (randomized for each participant), and the assignment of a test item to a particular RC-length priming condition was counterbalanced across subjects.

Following the main reading and comprehension task, all participants completed the AQ and an automated version (Unsworth et al. 2005) of Daneman and Carpenter's (1980) reading span task, a widely used measure of verbal working memory capacity. The entire experiment lasted approximately 50 min.

Participants

Participants were 102 (68 female, 34 male) native speakers of American English. They were students at the University of California, Los Angeles (UCLA) and received either monetary compensation or course credit. All participants confirmed that they were never diagnosed with a communication disorder, and all had normal or corrected vision.

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3.2 Results

We analyzed attachment decisions that were given by subjects within two standard deviations of the group's mean response time. Mixed-effects logistic regression (using the *glmer* function in the *lme4* package (Bates et al. 2013) of *R* (R Development Core Team 2013)) was used to model the probability of participants' "high-attachment" responses, with participant and item modeled as random effects. In addition to the experimental manipulation (length of the RC in the prime sentences), the fixed effects also included several stimulus- and participant-based factors. Stimulus variables included the length (in syllables) of the NPs and the RC in the target sentences, the order of the presentation of answers (i.e., NP1 appears on left or right), and experimental trial. Participant-level variables included gender (self-identified), reading span score (henceforth RSPAN), and AQ-Comm scores (calculated as a four-point Likert-scale; see Baron-Cohen et al. 2001). A preliminary model contained all of these predictors, and two-way interactions between prime condition and each of the other predictors. Then, predictors with a p value larger than 0.1 were removed if this did not result in a significant decrement to the fit of the model as determined by a likelihood-ratio test (e.g., Baayen 2008). The simplest, best fitting model was the one retained.

The results of the final model are shown in Table 1. There was a nonsignificant tendency for participants to give fewer high-attachment responses when the question ordered the NPs in the opposite order that they appeared in the sentence. Although there was no effect for AQ-Comm (as indicated by its high p value in the first round of modeling), RSPAN had a significant main effect with a negative coefficient value, indicating that participants with lower RSPANs were more likely to give high-attachment responses overall. This effect, consistent with Swets and colleagues' (2007) findings—and also consistent with the Implicit Prosody Hypothesis—is shown in Fig. 1. There was, however, no effect for priming condition; attachment preferences did not differ significantly depending on the length of the RC in the prime sentences. Indeed, as can be seen in the model's coefficients, there was a trend in the opposite direction in the Long RC condition, inconsistent with the IPH. That is, relative to the high-attachment response rate following the primes containing medium-length RCs (our control condition), participants were numerically less likely to give a high-attachment response after reading primes with long RCs.

Table 1 Estimates, standard errors, z and p values for Experiment 1. Positive estimates indicate the amount of increase in log-odds relative to the Intercept. For each categorical predictor, the change from the intercept is for the value given in parentheses

	β	SE (β)	z	p
(Intercept)	0.47			
Order (NP1 = left)	0.622	0.377	1.65	0.099
RSPAN	–0.025	0.011	–2.30	**0.022**
Prime length (long)	–0.247	0.152	–1.63	0.104
Prime length (short)	0.082	0.149	0.55	0.580

RSPAN reading span score, *NP* noun phrase

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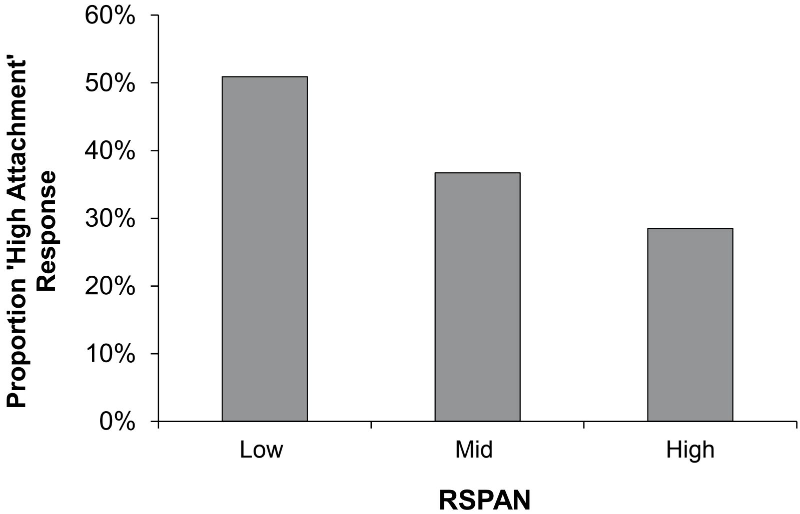

Fig. 1 Proportion of high-attachment responses as a function of participants' reading span score. The three levels refer to the group distribution, "Mid" being those subjects scoring within 1 standard deviation (SD) of the mean, the "Low" and "High" below or above 1 SD.

3.3 Discussion

The goal of Experiment 1 was to test whether prime sentences with longer RCs, which should be more likely than sentences with shorter RCs to contain an implicit prosodic boundary, influenced how participants parsed the RC in novel target sentences. If the implicit boundary were present in the prime sentences, and carried over to the novel sentence, we predicted this would result in a greater probability of the RC's being attached high in the target. However, we are faced with a null result from the experiment with respect to our manipulation (the only significant finding being the main effect for RSPAN, a replication of Swets et al.'s (2007) result); indeed, there was a trend in the opposite direction than predicted, with targets tending towards high attachment less often following long primes.

While it is possible that no priming was found in Experiment 1 because no implicit prosodic boundaries were in fact generated in the primes, we find this possibility unconvincing, for the reasons laid out in Sect. 2.1. Instead, it is more likely that priming did not occur either because (a) prosodic structure priming is inherently weak, as suggested by Tooley et al. (2013) or (b) there was something about our task which obscured or further weakened priming that would otherwise have been observable. We believe that both of these factors may be responsible.

Our intent was to manipulate what has been the most reliable predictor of both prosodic boundary placement and high-attachment preferences, namely RC length. However, it may be the case that the 9–12-syllable length for the long-RC condition

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was excessively long, making the modest 6–7-syllable-long RCs in the target sentences seems short in comparison. It may thus be that participants in the reading task, after reading a prime in the long-RC condition, treated targets as if they were short RCs, thus projecting no boundary before the RC. If this were the case, we would expect to see an effect in the opposite direction. In fact, this is what was found, although the trend was insignificant ($p = 0.10$).

Additionally, since Tooley et al. (2013) found prosodic priming to be weak (possibly too weak to be observed in truly novel sentences at all), it may be that a simple reading task does not result in sufficiently salient prosodic structures. In Experiment 2, we attempted to circumvent both of the possible pitfalls of the task used in Experiment 1 by presenting subjects with auditory primes—i.e., explicit prosody. The goal in Experiment 2 was therefore to test whether hearing a sentence with a prosodic boundary in a certain location influenced the comprehension of silently read sentences, and if the predictions of the IPH are useful in understanding any patterns.

4 Experiment 2: Explicit-to-Implicit Prosodic Priming

4.1 Methods

Stimuli

The basic design of sentence materials for Experiment 2 was similar to those for Experiment 1. For Experiment 2, targets were 18 sentences intended to lack any kind of biasing information, grammatical, or otherwise, and were again directly used or were modified version of sentences that have been normed in previous studies. Unlike the target sentences used in Experiment 1, however, these 18 target sentences contained RCs that were of one of two different lengths: shorter (3–5 syllables) or medium length (6–7 syllables).

The purpose of the primes for Experiment 2 was to deliver different explicit prosodic structures to participants, and so auditory prime sentences were created. The 16 prime sentences were, as other sentences in this study, based on those used in previous studies, and contained RCs (short, 3–5 syllables) with ambiguous attachment to a preceding NP. An example of one such prime was “The chef couldn’t find the lid of the pan that was clean” (see Appendix B for the full list); three versions of such primes were produced and recorded by a native speaker of English from California with extensive training in intonational phonology; each version was intended to manipulate the location of a prosodic boundary as shown schematically in (4). Example f0 contours for a prime in each of the three conditions are shown in Fig. 2. The control condition contained no large prosodic boundary—i.e., the prosodic juncture between each pair of words in the sentence was equal, i.e., by having a break index 1 in English ToBI (Beckman and Hirschberg 1994).

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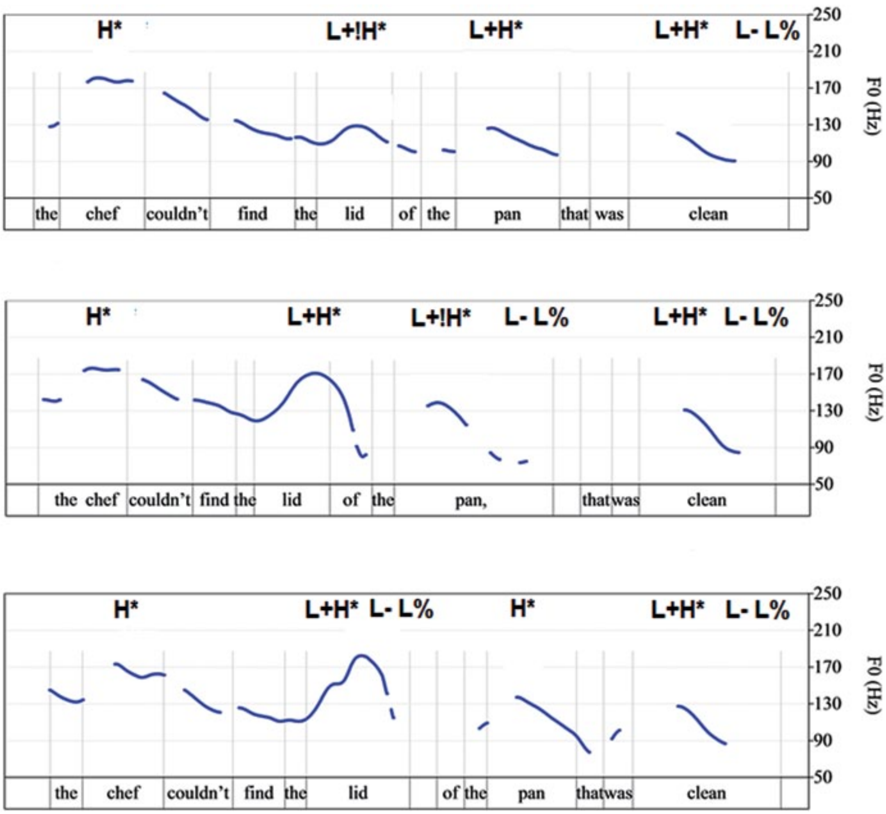

Fig. 2 Example of an auditory prime for Experiment 2, in each of the experimental conditions: no boundary/control (*top*), late boundary (*middle*), and early boundary (*bottom*). Accent status (accented/unaccented) was held constant across boundary conditions

(4) (a) boundary condition (control)
(…NP1 NP2 RC)
(b) Late boundary condition
(…NP1 NP2)//(RC)
(c) Early boundary condition
(…NP1)//(NP2 RC)

The boundaries used were the largest in the intonational phonological model for English, namely the Intonational Phrase (Pierrehumbert 1980; Beckman and Pierrehumbert 1986) and were marked by low f0 targets in each case (the L-phrase accent and L% boundary tone in the English ToBI conventions; Beckman and Hirschberg 1994). Additionally, accent status was held constant across the conditions such that pitch accents of the type (L+)H* (downstepped on NP2 in the late boundary condition) occurred on each of the two NPs, and one single-pitch accent occurred in the RC. Filler

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trials included sentences with RCs that had unambiguous attachment (i.e., there was only one head noun, or there was only one semantically plausible head noun), as for Experiment 1; filler primes, however, were designed to manipulate the location of an intonational phrase boundary in sentences lacking any RC. For example, filler primes were of the form "Jackie telephoned Paul between lunch and dinner." which (on different trials) contained either no boundary, a boundary after the subject, or a boundary after the direct object.

Procedure

A MATLAB script was used to present participants with the prime sentences, target sentences, and the questions that elicited their attachment decisions about the targets. Each trial proceeded as follows. First, three (different) prime sentences from the same boundary condition were presented, one after another with a short (0.5 s) interval between them. Then, following the offset of the third prime, a target sentence appeared on the screen. Finally, after 2.5 s, the standard attachment question appeared below the target sentence, and both the target and question remained on the screen until the participant selected an answer, which then began the next trial. Following this auditory priming task, participants completed the RSPAN task and AQ questionnaire; Experiment 2 took approximately 40 min to complete.

Participants

Participants were 120 (74 females, 46 males) native speakers of American English. They were undergraduate students at UCLA and received either monetary compensation or course credit. None had participated in Experiment 1, and all confirmed they had normal hearing, were never diagnosed with a communication disorder, and all had normal or corrected vision.

4.2 Results

The outcome variable "high-attachment response" was modeled as in Experiment 1, using the same factors, except that (a) the prime-related factor was boundary location rather than prime RC length, and (b) length of the RC in targets was a factor in Experiment 2 (Both boundary location and RC length were permitted to enter into three-way interactions with RSPAN and AQ scores in our models). The resulting model, following the procedures from Experiment 1, included the factors shown in Table 2.

Results showed the following; first, there was a main effect of RC length (in the target); consistent with previous work, target sentences containing shorter RCs were associated with fewer high-attachment responses ($p < 0.01$). There was also a robust main effect for the prosodic manipulation, i.e., the location of the prosodic break in

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Table 2 Estimates, standard errors, *z* and *p* values for Experiment 2. Positive estimates indicate the amount of increase in log-odds relative to the Intercept. For each categorical predictor, the change from the intercept is for the value given in parentheses

	β	$SE(\beta)$	z	p
(Intercept)	0.164			
RC length (short)	–0.889	0.335	–2.651	**0.008**
Boundary (early)	–0.702	0.583	–1.203	0.229
Boundary (late)	–1.686	0.584	–2.886	**0.003**
AQ-Comm	0.033	0.036	–0.902	0.367
Boundary (early) × AQ-Comm	0.028	0.030	0.919	0.358
Boundary (late) × AQ-Comm	0.085	0.030	2.860	**0.004**

RC relative clause, *AQ* autism spectrum quotient

the prime sentences. The effect, however, was in the opposite direction predicted by the IPH: Overall, targets following primes with a late prosodic boundary were associated with a lower rate of high-attachment responses by participants (relative to the control condition; $p<0.01$). Finally, although the AQ was not a significant predictor as in Experiment 1, the best-fitting model for Experiment 2 included a two-way interaction between AQ-Comm and boundary location, indicating that the effect just described was modulated by AQ-Comm scores. In particular, the probability of participants giving a high-attachment response to targets following late boundary primes (i.e., the pattern predicted by the IPH) was directly related to AQ-Comm scores. That is, the pattern predicted by the IPH was present, but limited to those subjects with more autistic-like communication skills. This pattern can be seen in Fig. 3. Also apparent in the figure is a (nonsignificant) trend in the direction of high AQ individuals being less likely to interpret the RC as attaching high in a target if that target was read after hearing primes with a break between the two NPs (i.e., early boundary) compared to the control prime. Note that RSPAN is not included in the best-fitting model because it was not a significant predictor of attachment. Further, it did not correlate with AQ-Comm ($r=-0.02$, $p>0.33$).

4.3 Discussion

The purpose of Experiment 2 was to test for the influence of prosodic boundaries in auditory prime sentences on the parsing of RCs in silently read sentences. The results indicate that there was such an influence, but the details are highly surprising. First, as a group, after hearing RC-sentences with a prosodic boundary after the second of two NPs, participants were actually more likely to attach the RC low to NP2 in an analogous target sentence; this priming effect is exactly the opposite of what we predicted based on the IPH. However, the second finding was that a subset of participants was more likely to attach the RC high after hearing sentences with late-occurring prosodic boundaries (also showing a trend towards attaching low after hearing sentences with an early occurring prosodic boundary), in line with our IPH-based predictions. What is surprising about the second finding is that these

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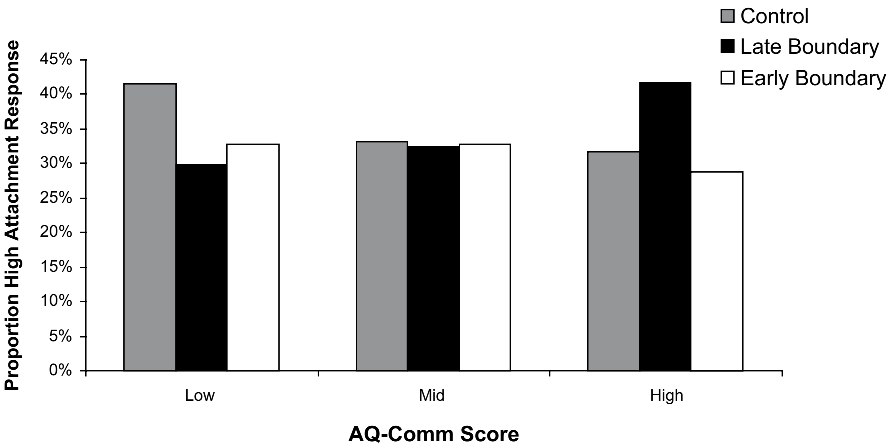

Fig. 3 Proportion of high-attachment responses for each boundary condition, shown for three groups of subjects according to their AQ-Comm score. The three levels refer to the group distribution: "Mid" is for those subjects scoring within 1 SD of the mean, and the "Low" and "High" levels are below or above 1 SD (the "mid" condition represents approximately 50 % of the participants, and the other two groups approximately 25 % each). Higher AQ-Comm scores reflect more prominent autistic traits in the communication dimension (the control condition in the figure represents primes without any prosodic break). *SD* standard deviation, *AQ* Autism spectrum quotient

were the participants with the most autistic-like communication skills, usually associated with lower sensitivity to prosody. The results are therefore quite puzzling from the perspective of the hypotheses we were testing.

We first address the primary finding, i.e., the main effect showing late boundaries to prime low attachment in targets, for which there are two basic logically possible interpretations. The first is that the prosodic boundary separating NP2 and the RC had the direct effect on syntactic parsing of cueing structural proximity, i.e., the lack of syntactic juncture. This interpretation is in such clear contradiction to previous research on the prosody–syntax relation as to render it untenable, and so we do not consider it further here. The second possibility, however, is that there was a cue relevant to attachment disambiguation concomitant with the location of prosodic boundaries in our design; we believe that such a correlate of our intended manipulation was in fact responsible, and that it was prosodic prominence.

Prosodic prominence, i.e., phrase-level accentuation, has been found previously to influence RC attachment decisions by Shafer et al. (1996; see also Lee and Watson 2011). In their study, using a traditional off line attachment decision task similar to ours, the authors presented participants with auditory sentences (as targets, not primes, as in our experiment) with a single prosodic boundary after NP2. In one experiment, it was shown that if only one of NP1 or NP2 contained a pitch accent, a strong bias was observed towards parsing the accented NP as the head of the RC. In a second experiment, holding accent location constant on NP2, the authors manipulated accent type, comparing a nuclear H* with a phonetically (and perceptually; see Turnbull et al. 2014) more prominent nuclear L+H*, and

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found that NP2 with L+H* triggered more RC attachment. Thus, increasing the prominence of NP2 through either accent status (i.e., [± accent]) or accent type increased also its likelihood of being parsed as the head of the RC.

In our Experiment 2, the manipulation of prominence was an inevitable result of manipulating boundary location. Recall that in the auditory primes, accent status for NP1 and NP2 was held constant, as was the fact that a single-pitch accent occurred within the RC across phrasing conditions. This being the case, the location of boundaries determines which of the accent on the two NPs is nuclear and which is prenuclear, a distinction in structural prominence (Beckman 1986; Beckman and Edwards 1994), which is illustrated schematically in (5), with nuclear accents in bold:

T* **T*** **T***
(5) (a) (…NP1 NP2)//(RC) *Late boundary, stronger NP2 prominence*
T* T* **T***
(b) (…NP1)//(NP2 RC) *Early boundary, weaker NP2 prominence*

What must be taken away from (5) is that structural prominence favors attachment to exactly the opposite head noun as does phrasing (given the IPH's working assumption (3a), noted in Sect. 1). It therefore seems, we conclude, that for the majority of listeners in our Experiment 2, prominence trumped boundary location in cueing attachment. This understanding of the main effect for phrasing in Experiment 2 also allows for a more intuitive interpretation of our finding that phrasing is a better predictor for individuals with high AQ-Comm scores—previously equated to poor pragmatic processing (Nieuwland et al. 2010; Xiang et al. 2013). That is, our finding is not because these individuals were especially sensitive to phrasing for the purposes of syntactic parsing, but that they were *less* sensitive to prominence than the rest of the group. This is more in line with Bishop's (2012b, 2013) findings in cross-modal priming, described at the end of Sect. 2.3. While we speculate that high AQ-Comm may therefore be associated with poor use of prosodic prominence, we do not suggest that our results should be interpreted as suggesting these individuals have an enhanced or even typical sensitivity to phrasing, a matter which we comment on further below.

5 General Discussion

The purpose of the present study was to explore a basic prediction of the Implicit Prosody Hypothesis about how prosody influences syntactic disambiguation in silent reading. According to Fodor's (2002) conceptualization, a large prosodic boundary, implicitly projected onto a sentence, should cue a large syntactic boundary at that location. In two experiments, we attempted to test this relationship between phrasing and parsing; although we did not generate a statistically significant finding in Experiment 1, in which we attempted to use (length-induced) implicit prosodic boundaries, we did find that explicit prosodic boundaries in primes in Experiment 2 influence parsing. Surprisingly, however, for the majority of our subjects, the pat-

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tern was in the opposite direction from what the IPH predicts. Nonetheless, having found prosody to be a significant predictor of ambiguity resolution in RC attachment, we do not believe that the results of that experiment invalidate the fundamental proposal embodied by the IPH. Rather, it suggests that it needs to be revised so as to take into account a wider range of prosodic structure; as discussed in the previous section, we believe we can appeal to patterns of prosodic prominence to explain the patterns of syntactic parsing observed in Experiment 2.

On this point, it must be emphasized that Fodor and her colleagues did not fail to consider the relevance of prosodic prominence in crafting their proposal about implicit prosody's role in sentence processing. Rather, they selected a methodological approach that sought, perhaps temporarily, to limit the investigation to phrasing, since phrasing would seem to be least confounded with semantic and information structural factors. What we believe our findings indicate is that this approach may simply not be tenable, not only because we know that prominence influences parsing but also because prominence and phrasing are closely linked aspects of prosodic structure.

It thus follows that the emphasis on the relation between syntax and phrasing to the exclusion of prominence—which we understand to be quite standard—is likely to be misguided. Having found the behavioral outcome of our phrasing manipulation in Experiment 2 to be better explained by the prominence contrast that accompanied it, we wonder how well prominence might account for previous findings as well. Certainly we see a plausible explanation for the results of Jun (2010), one of the original motivations for the present study. As discussed in Sect. 1, Jun found speakers of English, a low-attachment language, to prefer placing a boundary before NP2, the pattern predicted by the IPH for high-attachment languages. Jun reports that both NP1 and NP2 were always pitch accented, thus suggesting that NP2s, being phrase final, were nuclear accented, and therefore placed in a structurally prominent position by her speakers. This is in fact what we would expect from a low-attachment language if prominence (explicit or implicit) rather than phrasing were central. Similarly, this understanding would also help us make sense of the Japanese and Korean data from the earlier studies. In those studies (Jun and Koike 2003; Jun and Kim 2004; Jun 2007), prosodic boundaries were so crucial to predicting native speakers' high-attachment preferences (in a way predicted by the IPH) because these languages are edge-marking languages—unlike English, which is a head-marking language. In the prosodic typology proposed in Jun (2005, 2014), English, as a lexical stress language, marks prominence by pitch accenting, i.e., marking the *heads* of prosodic constituents, but Korean and Japanese encode prominence in boundaries, i.e., by tonally marking *edges* of prosodic constituents and/or by positioning a prominent word at the beginning of a prosodic constituent. This happens because Korean, lacking lexical prosody, lacks a *head* of a word; in Japanese, some but not all words have a lexically assigned pitch accent, but word edges are reliably marked by a rising tone (Beckman and Pierrehumbert 1986; Pierrehumbert and Beckman 1988; Warner et al. 2010). Thus, sensitivity to boundaries for syntactic parsing is most apparent in languages with edge marking, but not necessarily head-marking, prosody.

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In summary, then, if we revise Fodor's claim about the relation between prosody and parsing to include a wider range of prosodic structure—*and we allow the dominant aspect of that structure to be fixed typologically*—the basic proposal of the IPH finds support in the results of our study.

We also wish to make some brief comments on our findings related to autistic traits—a conspicuous and surprising part of the study. As described in our discussion of Experiment 2's results, we have concluded that the high AQ-Comm individuals may have been largely ignoring prominence patterns, and this is the primary way that they differed from other subjects. However, this would leave open the possibility that this sample of participants therefore used phrasing in the way that the IPH predicts, i.e., prosodic juncture was used to posit syntactic juncture, and, unlike other participants, they were simply not "distracted" by prominence. While we leave open this possibility, we believe a less-positive scenario might also explain their responses. This is one in which the parsers of high-AQ individuals, rather than productively using prosodic juncture to posit a syntactic boundary, were simply disrupted by the juncture—prompting closure at that location. While the distinction between this disruption-prompted closure and the effect of prosodic boundaries already assumed by the IPH may seem subtle (see Ferreira and Karimi, this volume, for insightful discussion of this matter), something along these lines would be necessary if it were found that the same individuals do not have the same boundary-attachment correspondences in their productions. We leave this question open for further research.

Finally, while the results of our structural priming study demonstrate a significant relation between prosodic structure and attachment resolution, we have until now left unspecified the details regarding the mechanism responsible. In particular, it is not yet clear whether the structure that was primed was in fact prosodic or syntactic, and in fact it cannot be teased apart in our Experiment 2. This is because the auditory primes had, in principle, two opportunities to influence participants' comprehension of the target sentences. For example, participants may have first assigned a syntactic structure to the primes, based on their overt prosody, and then reassigned this syntactic structure—but not the prosodic structure—to the target sentence. In this case, the prosody–syntax relationship is still confirmed, but prosody's influence took place at the parsing of primes, not the parsing of targets (and thus was syntactic priming in the usual sense). On the other hand, a scenario is also possible whereby listeners retained the prosodic structure from the primes, reusing that structure for the implicit prosody projected onto the silently read target sentence, and it was at this point that the prosody had its impact on ambiguity resolution for the target.

It is also possible, and in our opinion probable, that both types of priming took place. For the moment, we must be satisfied to have shown that prosody, at some point in the process, influenced attachment resolution systematically. In other work, however, we are currently attempting to tease the two possibilities apart. While this represents work in progress, we are optimistic that prosodic priming will in fact be demonstrable using a paradigm like the one used here, which, unlike Tooley et al.'s (2013) approach, does not involve the additional complications associated with eliciting speakers' productions.

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6 Conclusion

In conclusion, this study utilized novel prosodic adaptations of the structural priming paradigm. Our primary finding comes from Experiment 2, where it was demonstrated that the location of a prosodic boundary in auditory primes influenced the attachment of the RC in silently read target sentences. The correlation between boundary location and attachment, however, was in the exact opposite direction predicted by the Implicit Prosody Hypothesis for most of our subjects. Our proposed interpretation of these results relies on a more holistic consideration of prosodic structure, one in which structural prominence is a key factor, as well as a typological difference in prominence marking across languages. Our results, therefore, have crucial implications for future work on Fodor's influential Implicit Prosody Hypothesis, and indeed future work on the relationship between prosody and the processing of syntactic structure in general.

7 Appendix A: Experimental Stimuli for Experiment 1

7.1 Target Sentences

1. Linda wrote to the managers of the assistants that are late all the time.
2. My friend met the aide of the detective that was fired yesterday.
3. Nobody noticed the bodyguard of the actor that was talking on the phone.
4. The reporter interviewed the son of the colonel that had a car accident.
5. The woman knew the photographer of the singer that was reading a book.
6. Patricia saw the teachers of the students that were in class today.
7. Rob talked to the coach of the gymnast that was sick on Saturday.
8. Charlie met the interpreter of the ambassador that was eating dinner.
9. Roxanne read the review of the play that was written by John's friend.
10. The receptionist greeted the clients of the lawyers that were chatting loudly.
11. Jane wrote a story about the uncle of the milkman that was a gentleman.
12. Julia had spoken to the secretary of the doctor that was on vacation.
13. The journalist talked to the daughter of the hostage that was about to leave.
14. Lisa couldn't find the refills of the pens that were in the bottom drawer.
15. Someone shot the servant of the actress that was on the balcony.
16. The dog bit the mother of the teacher that lived in the South of France.

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7.2 Prime Sentences

Short Primes

S1. The nurse called in the sister of the hostess that got hurt.
S2. Everybody ignored the stepfather of the monk that had a beard.
S3. The drunk man hit the brother of the neighbor that was yelling.
S4. Lucy admired the hallways of the apartments that were painted.
S5. The chef couldn't find the lid of the pan that was clean.
S6. Ivana hated the father of the delegate that smokes.
S7. Andy ate with the cousin of the dentist that was divorced.
S8. I was talking with the niece of the midwife that lost weight.
S9. The children followed the aunt of the girl that wore a skirt.
S10. The thief took the key of the trunk that was outside.

Medium Primes

M1. Everybody ignored the stepfather of the monk that had a silky white beard.
M2. The driver talked to the guides of the tourists that were angry at the bird.
M3. Ivana hated the father of the delegate that always smokes cigarettes.
M4. Andrew had dinner with the nephew of the butler that loved his former job.
M5. The children followed the aunt of the girl that wore a yellow skirt.
M6. Peter met the uncle of the guest that was a famous chef.
M7. Andy ate with the cousin of the dentist that got divorced last April.
M8. Laura consoled the grandson of the general that lost his right arm and leg.
M9. The drunk man hit the brother of the neighbor that was yelling at the dog.
M10. Mary replaced the wire of the amplifier that got damaged last week.

Long Primes

L1. Peter met the uncle of the guest that was the most famous chef in Los Angeles.
L2. The nurse called in the sister of the hostess that got hurt in a terrible boat accident.
L3. The driver talked to the guides of the tourists that were angry at the restaurant owner.
L4. Lucy admired the hallways of the apartments that were painted light blue and lavender.
L5. The chef couldn't find the lid of the pan that was cleaned after the party in the evening.
L6. Laura consoled the grandson of the general that lost his leg during the Iraq war.
L7. Andrew had dinner with the nephew of the butler that loved his former job in Beverly Hills.
L8. I was talking with the niece of the midwife that lost weight before Maria’s wedding.
L9. The thief took the key of the trunk that was outside of the bedroom next to the door.
L10. Mary replaced the wire of the amplifier that has been damaged since last Halloween.

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8 Appendix B: Experimental Stimuli for Experiment 2

8.1 Target Sentences

3–4 syllables
1. My friend met the aide of the detective that was fired.
2. Linda wrote to the managers of the assistants that were late.
3. Jamie had inspected the monitor of the computer that was stolen.
4. Rob talked to the coach of the gymnast that was sick.
5. Patricia saw the teachers of the students that were in class.
6. The plumber adjusted the pipe of the sink that was cracked.
7. Charlie met the interpreter of the ambassador that was eating.
8. The dog bit the mother of the teacher that lived in France.
9. The receptionist greeted the clients of the lawyers that were chatting.

6–7 syllables
1. Jane wrote a story about the uncle of the milkman that was a gentleman.
2. Someone shot the servant of the actress that was on the balcony.
3. Roxanne read the review of the play that was written by John’s friend.
4. The woman knew the photographer of the singer that was reading a book.
5. The reporter interviewed the son of the colonel that had a car accident.
6. Nobody noticed the bodyguard of the actor that was talking on the phone.
7. Julia had spoken to the secretary of the doctor that was on vacation.
8. The journalist talked to the daughter of the hostage that was about to leave.
9. Lisa couldn’t find the refills of the pens that were in the bottom drawer.

8.2 Prime Sentences

1. Peter met the uncle of the guest that was a boxer.
2. The nurse called in the sister of the hostess that hurt herself.
3. Everybody ignored the stepfather of the monk that had a beard.
4. Linda helped to carry the baby of the lady that was upset.
5. The drunk man hit the brother of the neighbor that was yelling.
6. The driver talked to the guides of the tourists that were angry.
7. Lucy admired the hallways of the apartments that were painted.
8. The chef couldn't find the lid of the pan that was clean.
9. Ivana hated the father of the delegate that was smoking.
10. Laura consoled the grandson of the general that lost his leg.
11. Andy ate with the cousin of the dentist that was divorced.
12. Andrew had dinner with the nephew of the butler that loved his job.
13. I was talking with the niece of the midwife that lost her ring.
14. The children followed the aunt of the girl that wore a skirt.
15. The thief took the key of the trunk that was outside.
16. Mary replaced the wire of the amplifier that was damaged.

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