

Priming Implicit Prosody: Prosodic Boundaries and Individual Differences

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Abstract

Using the structural priming paradigm, the present study explores predictions made by the implicit prosody hypothesis (IPH) by testing whether an implicit prosodic boundary generated from a silently read sentence influences attachment preference for a novel, subsequently read sentence. Results indicate that such priming does occur, as evidenced by an effect on relative clause attachment. In particular, priming an implicit boundary directly before a relative clause – cued by commas in orthography – encouraged high attachment of that relative clause, although the size of the effect depended somewhat on individual differences in pragmatic/communication skills (as measured by the Autism Spectrum Quotient). Thus, in addition to supporting the basic claims of the IPH, the present study demonstrates the relevance of such individual differences to sentence processing, and that implicit prosodic structure, like syntactic structure, can be primed.

Keywords

Structural priming, implicit prosody, relative clause attachment, comma, autistic traits

Introduction

1.1 Implicit prosody in relative clause attachment

In this paper, we consider the syntactic ambiguity involving the attachment of relative clauses (RC) in sentences such as (1), in which the RC can be parsed as attaching high to NP (noun phrase) 1 *the servant*, or low to NP2 *the actress*:

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

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Although structurally ambiguous, it is known that native speakers do not parse such sentences randomly, but instead show slight biases towards one or the other attachment sites. Across languages, the direction of this bias is known to vary (high attachment bias: e.g., Spanish (Cuetos & Mitchell, 1988); Dutch (Brysbaert & Mitchell, 1996); French (Zagar, Pynte, & Rativeau, 1997); Japanese (Kamide & Mitchell, 1997); German (Hemforth, Konieczny, Scheepers, & Strube, 1998); Greek (Papadopoulou & Clahsen, 2003); low-attachment bias: e.g., English (Frazier & Fodor, 1978); Norwegian, Romanian, and Swedish (Ehrlich, Fernández, Fodor, Stenshoel, & Vinereanu, 1999); Arabic (Quinn, Abdelghany, & Fodor, 2000)). It is also known that, within languages, native-speaker attachment decisions are sensitive to the sentence's prosodic characteristics, particularly the location of a prosodic boundary (Fodor, 1998; Frazier, Clifton, & Carlson, 2004; Jun, 2003; Kjelgaard & Speer, 1999; Lovrić, Bradley, & Fodor, 2001; Quinn, Abdelghany, & Fodor 2000; Schafer, 1997). These facts have been used to support the implicit prosody hypothesis (IPH) (Fodor, 1998, 2002), which states that, in silent reading (where prosody is "implicit", i.e., subvocal), a default prosodic contour is projected onto the sentence, influencing the resolution of syntactic ambiguity. Other things being equal, the parser is said to favor the syntactic analysis associated with the most natural (or "default") prosodic contour for the construction. Fodor claimed that speakers interpret a prosodic break before a RC as a marker of a larger syntactic boundary; this suggests that the human sentence parser would favor low attachment when a prosodic break occurs directly before NP2 (grouping it with the RC, as in (2a)), but would favor high attachment when a prosodic break occurs between NP2 and the RC (as in (2b)):

- (2) a. *Someone shot the servant // of the actress who was on the balcony.*
 b. *Someone shot the servant of the actress // who was on the balcony.*

1.2 Accessing implicit prosody

One challenge in studying implicit prosody involves determining what kinds of evidence should be brought to bear on its form. In their early investigations of its role on sentence processing, Fodor and colleagues (e.g., Lovrić, Bradley, & Fodor, 2000, 2001; Maynell, 1999; Quinn et al., 2000) assumed that implicit prosody was essentially equivalent to explicit (i.e., overtly spoken) prosody, such as that associated with an "out-of-the-blue" reading. However, subsequent production studies have investigated this assumption and indicate that this is not always the case. While studies of Japanese (Jun & Koike, 2003), Korean (Jun, 2007; Jun & Kim, 2004), and Spanish (Bergmann, Armstrong, & Maday, 2008) have shown explicit prosodic boundaries to correspond to attachment-based predictions about implicit boundaries, analogous studies in English have failed to do so. In particular, despite English's status as a language with a low-attachment bias (where an implicit boundary after NP1 is predicted), English speakers have been found instead to prefer placing a large prosodic boundary after NP2 (Bergmann, Armstrong, & Maday, 2008; Bergmann & Ito, 2007; Jun, 2010; Jun & Shilman, 2008). It therefore appears that, if they function as proposed by Fodor and colleagues, implicit prosodic representations may not be easily assessed using explicit prosody.

There is reason to believe, however, that a more reliable approach to studying implicit prosody may involve influencing it directly, and then observing the outcome on sentence processing. One possible way to accomplish this is to manipulate visual cues in reading materials, which has been shown to have an influence on individual differences in attachment. For example, studies have shown working memory capacity to be negatively correlated with a preference for high attachment when the target sentence is presented on a single line (e.g., Jun & Bishop, to appear; Payne et al., 2014; Swets, Desmet, Hambrick, & Ferreira, 2007).¹ This has been interpreted as evidence that

readers with lower working memory resources rely on a “chunking” strategy, and are more likely to insert an implicit prosodic boundary before the RC in order to shorten the sentence into smaller processing units. Supporting this interpretation is the fact that when the RC is presented on a separate line (i.e., an explicit orthographic cue to “chunking” is provided), readers prefer to attach that RC high, to NP1, regardless of their working memory capacity (Swets et al., 2007; Traxler, 2009).

These findings suggest that implicit prosodic juncture can be imposed via visual discontinuity, with the outcome on attachment consistent with the IPH. The line break employed by Swets and colleagues (2007) in their materials resembles another, more conventionalized cue to prosodic juncture in text: the orthographic comma. As previous authors have suggested based on reading time data (e.g., Hill & Murray, 2000; Hirotsani, Frazier, & Rayner, 2006; Staub, 2007; see Breen, 2014 for an insightful review), commas occur at locations where a reader would place a prosodic boundary if reading aloud. This is further corroborated by the fact that, in silent reading, commas elicit an Event related potentials (ERP) component very similar to the closure positive shift (Steinhauer, 2003), a brain response associated with the presence of overt prosodic boundaries (Steinhauer, Alter, & Friederici, 1999). Converging evidence thus indicates that commas are “the written manifestation of implicit boundaries” (Breen, 2014).

Aside from the use of visual/orthographic cues, another approach to manipulating implicit prosody would be to “prime” it, which some authors have recently attempted. One such study was carried out by Tooley, Konopka, and Watson (2013), who used auditory prime sentences to prime boundary location for overt productions. This attempt to use explicit prosody to prime explicit prosody revealed only weak, if any, priming effects, leading the authors to conclude that prosodic structure may be inherently less primeable than syntactic structure. However, Speer and Foltz (in press) present evidence that implicitly generated pitch accents can prime the perception of auditorily presented probe words. In their study, participants silently read sentence pairs that placed or did not place contrastive focus on the subject. After reading such a pair, participants were then presented with an auditory version of the subject, and had to decide whether it was the same one they had just read. That auditory probe was presented with prosody that either matched given the sentence just read, or did not. For example, after reading *Jacquelyn didn't pass the test. Belinda passed the test* (which places contrastive focus on the subject, *Belinda*), participants heard *Belinda* with either a prominent L+H* pitch accent, or without any accentuation. Speer and Foltz's findings were subject to some (systematic) individual differences, but suggested that the identification of auditory probes depended on their prosody matching the one expected given the previous sentence (e.g., following the contrastive context, a L+H* probe was more readily identified). This suggests participants had generated contrastive prosody when reading the contrastively focused subjects, and thus provides evidence that implicit accentual structure can prime the perception of explicit prosody.

In another recent study, Jun and Bishop (in press) report an experiment in which the goal was to use explicit prosody to prime implicit prosody. Using a prosodic adaptation of the reading-based structural priming paradigm (Bock, 1986; Loncke, Van Laere, & Desmet, 2011; Scheepers, 2003), they presented listeners with auditory sentence primes with ambiguous RCs, such as *Someone shot the servant of the actress who was on the balcony*. These primes were presented with a prosodic boundary either before or after NP2 (as in example (2), above). After hearing auditory primes with either one or the other prosodic structures, participants silently read a novel (but also ambiguous) RC sentence. Attachment decisions were then made about that silently read target. The prediction was that, if the primes' explicit prosody influenced the implicit prosody generated for the target sentence, this would be observable in those attachment decisions.

In fact, Jun and Bishop (in press) found that attachment decisions were highly predictable based on the primes, at least for a subset of participants. As predicted by the IPH, these participants were

more likely to interpret the silently read target as having a high-attaching RC if they had just heard an auditory prime sentence with a boundary after NP2. Interestingly, the subgroup in question consisted of participants with prominent “autistic” traits along the “communication” dimension, as measured by the Autism Spectrum Quotient (AQ) (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Such traits are associated with poorer communicative and pragmatic language skills, and have been found relevant to predicting performance on sentence processing tasks that rely heavily on the use of pragmatic inference (Nieuwland, Ditman, & Kuperberg, 2010; Xiang, Grove, & Giannakidou, 2013). However, autistic traits have also been associated with differences in sensitivity to prosody – in particular prosodic prominence – in a study by Bishop (2012; see also Bishop, 2013, chapters 2–3). This connection between autistic traits and explicit prosody raises the possibility that the differences in attachment preference reported by Jun and Bishop (in press) may also be related to prosody – either implicit or explicit. In particular, Jun and Bishop suggest that participants with more autistic-like communication skills may have been more sensitive to explicit prosodic boundaries because they were less sensitive to explicit patterns of prosodic prominence on head nouns; the relative prominence of the two head nouns is also known to influence attachment preference (Lee & Watson, 2011; Schafer, Carter, Clifton, & Frazier, 1996).

While the details regarding the role of autistic traits remain underspecified, Jun and Bishop’s (in press) results confirm a correlation that supports the basic prediction of the IPH. That is, the presence of an earlier boundary (after NP1) tends to cue low attachment, and a later boundary (after NP2) cues high attachment. What is unclear from that study, however, is what the mechanism is. In particular, it is unclear whether the priming that occurred was in fact priming of syntactic structure or of prosodic structure. For example, it is possible that the explicit prosody of the primes influenced how listeners parsed the syntax of those primes, and then that syntactic structure was re-used to parse the novel target sentence. This is syntactic priming in the typical sense (Bock, 1986). However, it is also possible that the explicit prosody of the primes had a more direct impact on the target sentences, by influencing the implicit prosody generated for them. This prosodic structure priming is conceptually distinct from syntactic priming. However, because either of these two scenarios is possible from Jun and Bishop’s study, it is unclear which is the correct one.

We take up this matter in the present study. In the experiment presented below, native English speakers took part in a more traditional (i.e., reading only) structural priming task, involving prime-target combinations that were intended to limit the effects of syntactic priming. While targets contained RCs with ambiguous attachment to a head noun (e.g., *Jennifer blackmailed the boss of the clerk that was dishonest*), the prime sentences were designed to lack this attachment ambiguity. Instead, RCs in primes modified a single possible head noun either restrictively or non-restrictively, such as in (3a) and (3b):

- (3) a. Prime sentence with a restrictive RC:
The newspaper reporter phoned the secretary who was annoyed.
 b. Prime sentence with a non-restrictive RC:
The newspaper reporter phoned the secretary, who was annoyed.

Using the restrictiveness contrast in our primes allows us to accomplish two important things, which we would now like to highlight separately.

First, because the contrast is primarily communicated by the presence versus absence of a prosodic boundary – cued by commas in orthography – it allows us to directly manipulate the presence of implicit boundaries in primes.² If the presence of an implicit boundary before the RC in a prime sentence were to carry over to the following target, we would expect this to be detectable in readers’ preferred parsings of the target. Based on previous findings (e.g., Carlson, Clifton, & Frazier,

2001; Swets et al., 2007; Watson & Gibson, 2004), we expect such primed boundaries to result in more high attachment of the target's RC.

Second, and crucially, using the restrictiveness contrast allows us to tease apart prosodic priming from syntactic priming effects (at least with respect to attachment). This is because both restrictive and non-restrictive primes had only one possible NP attachment site while targets had two. Recall that syntactic priming could not be ruled out in Jun and Bishop's (in press) previous study because attachment was ambiguous in both primes and targets. Thus, we argue that any divergent effects our primes have on the parsing of target sentences will be the result of their (implicit) prosodic phrasing, not their syntactic structure.

2 Method

2.1 Stimuli

Sixteen sentences containing RCs of medium length (4–6 syllables) were created to serve as target sentences to be read by participants. These sentences, based on sentences used in previous studies (e.g., Carreiras & Clifton, 1993; Dussias, 2003; Felser, Marinis, & Clahsen, 2003; Fernández & Bradley, 1999; Frazier, 1990; Frazier & Clifton, 1996), were designed to lack any grammatical or semantic bias favoring high or low attachment to a preceding object NP. It should be noted that in this way they differed from the sentences used in Swets et al. (2007), where the ambiguity involved attachment to a subject NP. A subset of the targets used is shown in Table 1 as examples (a full list of stimuli is provided in the Appendix).

Prime sentences, to be presented and read immediately before the targets, were also created, and were based on 30 sentences of similar length (to avoid any influence on parsing due to the length difference between primes and targets). Like targets, primes contained RCs that were 4–6 syllables in length, but they differed from targets in two ways. First, as noted above, the RCs in primes followed a single head noun, and so they had unambiguous attachment to that head noun. Second, there were two versions of each prime: one was to be interpreted as having a restrictive RC, and the other a non-restrictive RC. The non-restrictive RC was marked by the standard orthographic convention, that is, a comma preceding the RC; the restrictive RC versions lacked any such comma. A subset of primes used is shown in Table 1 (for the full list of primes used, see the Appendix).

2.2 Participants

Participants were 120 native speakers of American English, mostly undergraduate students. None of the participants reported any speech or communication disorders, and all received either course credit or monetary compensation.

2.3 Procedure

Participants read the prime and target sentences, then answered attachment questions. A MATLAB script was used to present participants with the sentence materials on a computer screen. On each experimental trial, the script selected one of the 16 target sentences and three prime sentences from one of the two prime conditions; three primes were used instead of a single one in the hope that it would produce more reliable priming. The participant then proceeded through the four sentences: each of the three primes (for which presentation order was randomized on each trial), then the target. This was done at the participant's own pace, pressing a computer key to remove one sentence from the screen and display the next. Following a key press after the target sentence, however, a question appeared, asking the participant the standard RC-attachment question (e.g., *Who*

Table 1. Example stimuli: ambiguous RC-sentence targets (A) and unambiguous primes with restrictive or non-restrictive RCs (B).

A	Example target sentences
1	Jennifer blackmailed the boss of the clerk that was dishonest.
2	Susanna was dating the cousin of the artist that was a veteran.
3	The lady mended the sleeve of the shirt that had been stained.
4	Robert pondered the map of the pyramid that was incomplete.
5	Alison was listening to the chirping of the bird that was pretty.
B	Example prime sentences (restrictive, without comma)
1a	The inspector photographed the boat's cover that was yellow.
2a	The coach looked at the varsity players who were very happy.
3a	The picky journalist hated the soldiers who were sitting down.
4a	The clumsy plumber changed the sink faucet that we installed.
5a	My husband framed the certificate that he received in the mail.
C	Example prime sentences (non-restrictive, with comma)
1b	The inspector photographed the boat's cover, which was yellow.
2b	The coach looked at the varsity players, who were very happy.
3b	The picky journalist hated the soldiers, who were sitting down.
4b	The clumsy plumber changed the sink faucet, which we installed.
5b	My husband framed the certificate, which he received in the mail.

RC: relative clause.

was on the balcony? in the case of (1), above), presenting the two possible head nouns as the options “A” and “B”. Whether the high attachment response (i.e., NP1) appeared on the left as “A” or on the right as “B” was counterbalanced across participants.

Filler trials (consisting of 28 filler targets and 30 filler primes) proceeded in the same manner as experimental trials, with the following exception. On filler trials, a question appeared for one of the three prime sentences, selected at random. This was to prevent participants from knowing exactly which sentence in a trial (i.e., every fourth sentence presented to them) would be the one requiring a response to a question, thus encouraging careful reading of primes on all trials.

Participants carried on through all experimental and filler trials (randomized for each participant, allowing for the detection of any effects for trial), and the assignment of a particular target sentence to a prime condition (restrictive versus non-restrictive RC) was counterbalanced across subjects. Following the reading task, participants then completed the AQ (Baron-Cohen et al., 2001), a 50-item self-report questionnaire that requires agree/disagree responses. The AQ is composed of five separate subscales, measuring *social skills* (“I would rather go to a library than a party”), *communication* (“I frequently find that I don’t know how to keep a conversation going”), *imagination* (“When I’m reading a story, I find it difficult to work out the characters’ intentions”), *attention to detail* (“I usually notice car number plates or similar strings of information”), and *attention-switching* (“I frequently get so absorbed in one thing that I lose sight of other things”). Both the reading task and the completion of the AQ took place in a quiet testing room. In total, the experiment took approximately 30 minutes.

3 Results

In order to understand any potential effects primes had on targets, two rounds of mixed-effects logistic regression modeling took place. The first was aimed at an overall test of the primary

Table 2. Estimates, standard errors, *z*- and *p*-values for the first model testing the effect of primes on high attachment responses. Positive estimates indicate the amount of increase in log-odds relative to the intercept.

Fixed effects:	β	SE	<i>z</i>	<i>p</i>
(Intercept)	-.389	.213	-1.83	<.1
Trial	.009	.003	2.55	<.05
Prime type (<i>non-restrictive</i>)	.220	.104	2.11	<.05

manipulation – that is, the implicit prosody of the prime sentences – without considering possible individual differences related to autistic traits. The second round of modeling included scores on each of the AQ subscales, although our primary interests were in the communication subscale (henceforth AQ-communication), which, as described above, has previously been shown to be relevant to sentence processing (Bishop, 2013; Jun & Bishop, in press; Nieuwland et al., 2010; Xiang et al., 2013).

The first round of modeling included only the contrasts “prime type” (non-restrictive vs. restrictive), “trial”, and the interaction between the two, with random intercepts for both “subject” and “item”).³ After removing non-contributing factors in the model (in this case the interaction term), the model was refitted. Results, shown in Table 2, indicated that primes did in fact influence how participants parsed the ambiguous RCs in targets. As predicted by the IPH, participants chose high attachment significantly more often after reading primes in the non-restrictive RC condition (which contained a comma before the RC) than after reading primes in the restrictive RC condition (which lacked any such visual/orthographic cue to a boundary), a difference of just under 4% (high attachment was 47.7% for the restrictive condition versus 51.6% for the non-restrictive condition). This suggests that the implicit prosody of primes influenced the implicit prosody of targets, which in turn influenced attachment resolution. Additionally, the significant effect of trial indicated that, as the experiment went on, high attachment responses became more likely overall.

The second round of modeling included trial, prime type, participants’ scores on each of the five subscales of the AQ, and interactions between prime type and each of these five scores. Again, we dropped non-contributing fixed-effects factors to achieve the simplest best fitting model. This model included terms for trial, prime type, AQ-attention switching, AQ-communication, and the interaction between prime type and AQ-communication. The results (see Table 3) showed the interaction between prime type and AQ-communication scores to be significant, with higher AQ-communication scores being associated with a stronger priming effect. That is, the more autistic-like the communication skills of the participants, the more likely they were to be influenced by the implicit boundary in the primes. (Figure 1 shows these patterns grouped by distribution, although AQ-related scores were continuous variables in the model). The second model also revealed a significant simple effect for scores on the AQ-attention switching subscale; as shown in Figure 2, higher scores (indicating poorer, more autistic-like attention-switching abilities) were associated with a greater likelihood of a high attachment response, regardless of prime condition. Finally, the significant effect of trial found in the simpler model also held here, indicating high attachment was, regardless of prime type, more likely on later trials.

4 Discussion

The structural priming experiment presented above was intended to test a basic prediction of the IPH (Fodor, 1998), which claims that a strong prosodic boundary generated implicitly during

Table 3. Estimates, standard errors, z- and p-values for the second model of high attachment responses, adding AQ subscales.

Fixed effects:	β	SE	z	p
(Intercept)	-1.797	.933	-1.93	<.1
Trial	.009	.004	2.45	<.05
AQ-attention switching	.096	.036	2.70	<.01
AQ-communication	-.052	.036	-1.45	n.s.
Prime type (<i>nonrestrictive</i>)	-.932	.511	-1.82	<.1
Prime type (<i>nonrestrictive</i>) × AQ-communication	.060	.026	2.30	<.05

AQ: autistic spectrum quotient

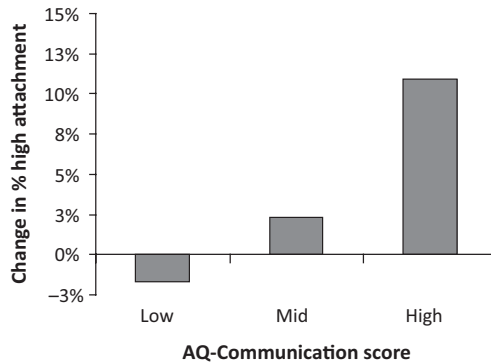


Figure 1. Increase in high attachment responses to targets in the non-restrictive relative clause (RC) prime condition (relative to the restrictive RC prime condition) as a function of autism spectrum quotient (AQ) communication scores. The three levels of AQ refer to the group distribution: “mid” are subjects scoring within 1 SD of the mean, the “low” and “high” levels below or above 1 SD.

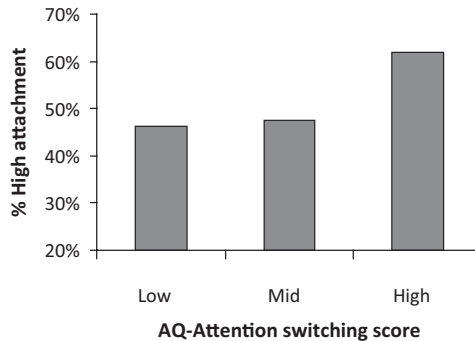


Figure 2. High attachment responses as a function of scores on the attention-switching subscale of the autism spectrum quotient (AQ). The three levels refer to the group distribution: “mid” are subjects scoring within 1 SD of the mean, the “low” and “high” levels below or above 1 SD.

reading influences the attachment of an RC. In particular, a strong prosodic boundary directly before the RC is predicted to encourage a high attachment parsing of that RC. In fact, after reading sentences designed to have such a boundary, participants in our experiment were more likely to attach the RC high in a novel sentence, to NP1. Importantly, unlike in Jun and Bishop (in press), the syntax of primes and targets did not match in our experiment (with respect to attachment possibilities). It is therefore clear that the parsings of targets were primed by prosodic structure (cued by commas), not syntactic structure. The two primary findings in our study are therefore (a) that implicit prosodic structure, like syntactic structure, can be primed, and (b) that silently generated prosodic boundaries can influence attachment as predicted by the IPH. The first finding is especially significant, as it demonstrates that prosody is in fact primeable, a matter which is somewhat unclear from recent literature (e.g., Tooley et al., 2013). The significance of our second finding lies in the fact that, although implicit prosody has been shown in many studies to influence sentence comprehension, claims about the role of phrasing on attachment preferences have been difficult to confirm. Notably, uncertainty surrounding both of these issues – the primeability of prosody and the relation between phrasing and attachment – may be due to previous studies' reliance on explicitly produced prosody. As is increasingly appreciated in the production literature, overt prosody does not always encode syntactic structure (e.g., Ferreira, 1993; Jun, 1998; Snedeker & Trueswell, 2003) and may not be identical in form to implicit prosody (e.g., Jun, 2010).

The results also add to a growing body of research indicating that autistic traits in the neurotypical population, at least those closely tied to pragmatic/communicative skills, predict sensitivity to prosody in sentence processing. In particular, participants with poorer, more autistic-like communicative skills showed a more dramatic priming effect, with their parsings of targets being more strongly influenced by implicit boundaries. This result echoes the one in Jun and Bishop (in press), where high AQ-communication scores were also positively correlated with sensitivity to (explicit) prosodic boundaries.

Out of hand, the finding that autistic-like processing is associated with increased sensitivity to prosody seems quite counterintuitive. However, we suspect that this apparent sensitivity is probably not best characterized as an adaptive one. Rather than indicating that these individuals use prosodic structure for assigning syntactic structure more effectively, it may be the case that they are simply more likely to copy the prosodic structure from the primes instead of generating their own representations for the target. It may also reflect processing that is more vulnerable to disruption – in the sense of Staub and Benatar (2013), where a disruption is a point at which continuous processing by the parser fails. Under this scenario, a prosodic boundary directly before the RC, rather than cueing syntactic attachment per se, disrupts syntactic structure building for these individuals. When such disruption occurs, we might speculate that the result is closure at that site. Under such a scenario we need only assume that the boundary that induces the disruption can be one that is primed.

The hypothesis that autistic traits may be associated with more limited processing resources is supported by a second finding related to autistic traits in our study. High scores on the attention-switching subscale of the AQ (i.e., worse attention-switching abilities) were associated with higher overall rates of high attachment (independent of the implicit boundary manipulation). The relation between attachment preference and attention-switching therefore resembles the one between attachment preference and verbal working memory in other offline reading studies (Jun & Bishop, in press; Swets et al., 2007), possibly because they both reflect similar general processing resources. That is, those with either lower working memory, or weaker attentional control, may be more likely to rely on a “chunking” approach to the input (Swets et al., 2007; see also Payne et al., 2014, who argue that attentional control underlines age-related differences on attachment bias). This interpretation is also consistent with the effect for trial found in our experiment; as an anonymous reviewer

points out, we might have predicted readers to tend towards the English default parsing over the course of the experiment, increasingly attaching low, to NP2. However, the effect for trial indicated that the opposite was true; high attachment preferences increased (regardless of experimental condition), suggesting participants may have preferred implicitly segmenting sentences into smaller chunks as the reading experiment wore on. While we feel these scenarios are highly plausible, it is also clear that further research is needed to understand the processing mechanisms underlying performance differences related to autistic traits.

In sum, the present study provides crucial evidence for the implicit prosody hypothesis regarding the relation between implicit prosodic boundaries and attachment resolution in reading. Further, we have shown that implicit prosodic structure, like syntactic structure, can be primed, and that the details of this priming depend on variation in autistic traits in the neurotypical population.

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Notes

1. Unlike studies such as Swets et al. (2007) and Jun and Bishop (in press), some studies using online methodology have found working memory to have the opposite relation to attachment preference (e.g., Traxler, 2007; but see Payne et al., 2014). Because our study utilizes reading and question-answering methodology, we limit our discussion of working memory effects on attachment to the results of offline investigations.
2. A reviewer points out that our two prime conditions might not be equally unambiguous with respect to the presence of a boundary (and thus restrictiveness); although the condition with a comma is unambiguously non-restrictive, the condition without an orthographic comma could be regarded as ambiguous between a non-restrictive and restrictive reading. This is because the restrictive version, lacking a comma, simply lacks an explicit orthographic cue to a boundary (which a reader could implicitly insert nonetheless). This is probably unavoidable, since the written language does not provide an explicit cue to the *absence* of a boundary. However, if our participants sometimes read restrictive primes as non-restrictive, this would mean that the differences between conditions we report (later in Section 3) are somewhat underestimated.
3. We report intercept-only models here, although, based on the recommendations in Barr, Levy, Scheepers, and Tily (2013), we also explored models with more random effects structure. For the second round of modeling, we found that adding a by-subject random slope for “trial” resulted in a marginally significantly better fit to the data. However, for clarity, and because it did not influence the pattern of results, we present the outcome of the simpler model here.

References

- Baron-Cohn, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism Spectrum Quotient (AQ): Evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders*, 31(1), 5–17.
- Barr, D., Levy, R., Scheepers, C., & Tily, H. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, 68, 255–278.

- Bergmann, A., Armstrong, M., & Maday, K. (2008). *Relative clause attachment in English and Spanish: A production study*. *Proceedings of Speech Prosody 2008*, Campinas, Brazil.
- Bergmann, A., & Ito, K. (2007). Attachment of ambiguous RCs: A production study. Talk given at the 13th annual conference on architectures and mechanisms for language processing (AMLaP), Turku, Finland, 24–27 August 2007.
- Bishop, J. (2012). Focus, prosody, and individual differences in “autistic” traits: Evidence from cross modal semantic priming. *UCLA Working Papers in Phonetics*, 111, 1–26.
- Bishop, J. (2013). *Prenuclear accentuation: Phonetics, phonology, and information structure*. Unpublished doctoral dissertation, University of California, Los Angeles.
- Bock, J. K. (1986). Syntactic persistence in language production. *Cognitive Psychology*, 18, 355–387.
- Breen, M. (2014). Empirical investigations of the role of implicit prosody in sentence processing. *Language and Linguistics Compass*, 8(2), 37–50.
- Brysbaert, M., & Mitchell, D. C. (1996). Modifier attachment in sentence parsing: Evidence from Dutch. *Quarterly Journal of Experimental Psychology*, 49A(3), 664–695.
- Carlson, K., Clifton, C., & Frazier, L. (2001). Prosodic boundaries in adjunct attachment. *Journal of Memory and Language*, 45, 58–81.
- Carreiras, M., & Clifton, C., Jr. (1993). Relative clause interpretation preferences in Spanish and English. *Language and Speech*, 36, 353–372.
- Cuetos, F., & Mitchell, D. C. (1988). Cross-linguistic differences in parsing: Restrictions on the use of the late closure strategy in Spanish. *Cognition*, 30, 73–105.
- Dussias, P. E. (2003). Syntactic ambiguity resolution in second language learners: Some effects of bilinguality on L1 and L2 processing strategies. *Studies in Second Language Acquisition*, 25, 529–557.
- Ehrlich, K., Fernández, E. M., Fodor, J. D., Stenshoel, E., & Vinereanu, M. (1999). Low attachment of relative clauses: New data from Swedish, Norwegian, and Romanian. Poster presented at the 12th annual CUNY Conference on Human Sentence Processing, New York, March 18–20.
- Felser, C., Marinis, T., & Clahsen, H. (2003). Children’s processing of ambiguous sentences: a study of relative clause attachment. *Language Acquisition*, 11, 127–163.
- Fernández, E. M. (2003). *Bilingual sentence processing: Relative clause attachment in English and Spanish*. Amsterdam, the Netherlands: John Benjamins.
- Fernández, E. M., & Bradley, D. (1999). Length effects in the attachment of relative clauses in English. Poster presented at the 12th annual CUNY conference on human sentence processing, New York.
- Ferreira, F. (1993). The creation of prosody during sentence production. *Psychological Review*, 100, 233–253.
- Fodor, J. D. (1998). Learning to parse. *Journal of Psycholinguistic Research*, 27(2), 285–319.
- Fodor, J. D. (2002). Prosodic disambiguation in silent reading. *Proceedings of NELS*, 32, 113–132.
- Frazier, L. (1990). Parsing modifiers: Special purpose routines in the human sentence processing mechanism? In D. A. Balota, G. G. Flores d’Arcais, & K. Rayner (Eds.), *Comprehension processes in reading* (pp. 303–330). Hillsdale, NJ: Lawrence Erlbaum.
- Frazier, L., & Clifton, C. (1996). *Construal*. Cambridge, MA: MIT Press.
- Frazier, L., Clifton, C., & Carlson, K. (2004). Don’t break, or do: Prosodic boundary preferences. *Lingua*, 114(1), 3–27.
- Frazier, L., & Fodor, J. D. (1978). The sausage machine: A new two-stage parsing model. *Cognition*, 6, 291–325.
- Hemforth, B., Konieczny, L., Scheepers, C., & Strube, G. (1998). Syntactic ambiguity resolution in German. In D. Hillert (Ed.), *Syntax and semantics: A cross-linguistic perspective* (pp. 293–312). San Diego, CA: Academic Press.
- Hill, R., & Murray, W. (2000). Atoning for punctuation: Prosody and ambiguity while reading aloud. Unpublished doctoral dissertation, University of Dundee.
- Hirotsani, M., Frazier, L., & Rayner, K. (2006). Punctuation and intonation effects on clause and sentence wrap-up: Evidence from eye-movements. *Journal of Memory and Language*, 54, 425–443.
- Jun, S.-A. (1998). The accentual phrase in the Korean prosodic hierarchy. *Phonology*, 15(2), 189–226.
- Jun, S.-A. (2003). Prosodic phrasing and attachment preferences. *Journal of Psycholinguistic Research*, 32(2), 219–249.

- Jun, S.-A. (2007) *The intermediate phrase in Korean intonation: Evidence from sentence processing*. In C. Gussenhoven, & T. Riad (Eds), *Tones and tunes: Studies in word and sentence prosody* (pp. 143–167). Berlin, Germany: Mouton de Gruyter.
- Jun, S.-A. (2010). The implicit prosody hypothesis and overt prosody in English. *Language and Cognitive Processes*, 25, 1201–1233.
- Jun, S.-A., & Bishop, J. (in press). Prominence in relative clause attachment: Evidence from prosodic priming. In L. Frazier & E. Gibson (Eds), *Explicit and implicit prosody in sentence processing: Studies in honor of Janet Dean Fodor. Vol. 46 of the Studies in Theoretical Psycholinguistics*. Springer.
- Jun, S.-A., & Kim, S. (2004). Default phrasing and attachment preferences in Korean. *Proceedings of Interspeech-ICSLP*, Jeju, Korea.
- Jun, S.-A., & Koike, C. (2003). Default prosody and RC attachment in Japanese. Talk given at the 13th Japanese–Korean Linguistics Conference, Tucson, AZ. [Published in *Japanese-Korean Linguistics 3*, 41–53, CSLI, Stanford, in 2008].
- Jun, S.-A., & Shilman, M. (2008). Default phrasing and English relative clause attachment data. *Proceedings of Speech Prosody 2008*, Campinas, Brazil.
- Kamide, Y., & Mitchell, D. (1997). Relative clause attachment: Non-determinism in Japanese parsing. *Journal of Psycholinguistic Research*, 26, 247–254.
- Kjelgaard, M. M., & Speer, S. R. (1999). Prosodic facilitation and interference in the resolution of temporary syntactic closure ambiguity. *Journal of Memory and Language*, 40, 153–194.
- Lee, E.-K., & Watson, D. (2011). Effects of pitch accents in attachment ambiguity resolution. *Language and Cognitive Processes*, 26(2), 262–297
- Loncke, M., Van Laere, S. M. J., & Desmet, T. (2011). Cross-structural priming: Prepositional phrase attachment primes relative clause attachment. *Experimental Psychology*, 58(3), 227–234.
- Lovrić, N., Bradley, D., & Fodor, J. D. (2000). RC attachment in Croatian with and without preposition. Poster presented at the AMLaP Conference, Leiden.
- Lovrić, N., Bradley, D., & Fodor, J. D. (2001). Silent prosody resolves syntactic ambiguities: Evidence from Croatian. Presented at the SUNY/CUNY/NYU Conference, Stonybrook, NY.
- Maynell, L. A. (1999). Effect of pitch accent placement on resolving relative clause ambiguity in English. Poster presented at the 12th Annual CUNY Conference on Human Sentence Processing, New York.
- Nieuwland, M., Ditman, T., & Kuperberg, G. (2010). On the incrementality of pragmatic processing: An ERP investigation of informativeness and pragmatic abilities. *Journal of Memory and Language*, 63, 324–346.
- Papadopoulou, D., & Clahsen, H. (2003). Parsing strategies in L1 and L2 sentence processing: A study of relative clause attachment in Greek. *Studies in Second Language Acquisition*, 25, 501–528.
- Payne, B., Grison, S., Gao, X., Christianson, K., Morrow, D., & Stine-Morrow, E. (2014). Aging and individual differences in binding during sentence understanding: Evidence from temporary and global syntactic attachment ambiguities. *Cognition*, 130, 157–173.
- Quinn, D., Abdelghany, H., & Fodor, J. D. (2000). More evidence of implicit prosody in reading: French and Arabic relative clauses. Poster presented at the 13th Annual CUNY Conference on Human Sentence Processing, La Jolla, CA, March 30–April 1.
- Schafer, A., Carter, J., Clifton, C., & Frazier, L. (1996). Focus in relative clause construal. *Language and Cognitive Processes*, 11, 135–163.
- Schafer, A. J. (1997). *Prosodic parsing: The role of prosody in sentence comprehension*. Ph.D. Dissertation, University of Massachusetts.
- Scheepers, C. (2003). Syntactic priming of relative clause attachments: Persistence of structural configuration in sentence production. *Cognition*, 89, 179–205.
- Snedeker, J., & Trueswell, J. (2003). Using prosody to avoid ambiguity: Effects of speaker awareness and referential context. *Journal of Memory and Language*, 48, 103–130.
- Speer, S., & Foltz, A. (in press). Implicit contrastive prosody: Individual differences in processing and production. In L. Frazier, & E. Gibson (Eds), *Explicit and implicit prosody in sentence processing: Studies in honor of Janet Dean Fodor. Vol. 46 of the Studies in Theoretical Psycholinguistics*. Springer.

- Staub, A. (2007). The parser doesn't ignore transitivity, after all. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33(3), 550–569.
- Staub, A., & Benatar, A. (2013). Individual differences in fixation duration distributions in reading. *Psychonomic Bulletin & Review*, 20, 1304–1311.
- Steinhauer, K. (2003). Electrophysiological correlates of prosody and punctuation. *Brain and Language*, 86, 142–164.
- Steinhauer, K., Alter, K., & Friederici, A. (1999). Brain potentials indicate the immediate use of prosodic cues in natural speech processing. *Nature Neuroscience*, 2, 191–196.
- Swets, B., Desmet, T., Hambrick, D. Z., & Ferreira, F. (2007). The role of working memory in syntactic ambiguity resolution: A psychometric approach. *Journal of Experimental Psychology: General*, 136, 64–81.
- Tooley, K., Konopka, A., & Watson, D. (2013). Can intonational phrase structure be primed (like syntactic structure)? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40(2), 348–363.
- Traxler, M. J. (2007). Working memory contributions to relative clause attachment processing: A hierarchical linear modeling analysis. *Memory and Cognition*, 35, 1107–1121.
- Traxler, M. J. (2009). A hierarchical linear modeling analysis of working memory and implicit prosody in the resolution of adjunct attachment ambiguity. *Journal of Psycholinguistic Research*, 38, 491–509.
- Watson, D., & Gibson, E. (2004). The relationship between intonational phrasing and syntactic structure in language production. *Language and Cognitive Processes*, 19(6), 713–755.
- Xiang, M., Grove, J., & Giannakidou, A. (2013). Dependency dependent interference: NPI interference, agreement attraction, and global pragmatic inferences. *Frontiers in Psychology*, 4, 708.
- Zagar, D., Pynte, J., & Rativeau, S. (1997). Evidence for early-closure attachment on first-pass reading in French. *Quarterly Journal of Experimental Psychology*, 50A(2), 421–438.

Appendix: full list of stimuli

1 Target sentences

- 1) Jennifer blackmailed the boss of the clerk that was dishonest.
- 2) Susanna was dating the cousin of the artist that was a veteran.
- 3) The lady mended the sleeve of the shirt that had been stained.
- 4) Robert pondered the map of the pyramid that was incomplete.
- 5) Alison was listening to the chirping of the bird that was pretty.
- 6) The clerk stared at the arm of the mannequin that needed paint.
- 7) Reporters interviewed the sister of the senator that was popular.
- 8) Lisa photographed the museum of the city that was in the news.
- 9) The policeman found the hubcap of the car that had been stolen.
- 10) Stacey wanted to invite the friend of the secretary that was Irish.
- 11) George questioned the brother of the minister that was divorced.
- 12) Carol's grandmother hiked the trail of the park that was crowded.
- 13) The officer contacted the restaurant of the hotel that was infested.
- 14) Stan waited in the checkout lane of the market that just opened up.
- 15) Janice kicked the speaker of the stereo that sometimes didn't work.
- 16) Hank had built the drum machine of the band that had disappeared.

2 Prime sentences

2.1 Restrictive RC condition

- 1) The inspector photographed the boat's cover that was yellow.
- 2) The coach looked at the varsity players who were very happy.

- 3) The picky journalist hated the soldiers who were sitting down.
- 4) The clumsy plumber changed the sink faucet that we installed.
- 5) My husband framed the certificate that he received in the mail.
- 6) The article failed to mention the library that had just been built.
- 7) The master looked at the innocent pupil who was standing still.
- 8) The architect designed the water slide that many children liked.
- 9) My uncle had to repair the bicycle tire that my mom purchased.
- 10) My brother smashed the rental-agency's open car that he hated.
- 11) The team leader showed us the bottle's label that they designed.
- 12) The reporter interviewed the bodyguard who looked handsome.
- 13) The lady from London disliked the player who didn't say much.
- 14) The newspaper described the ceremony that seemed very weird.
- 15) The early sun sparkled on the plane's propeller that was broken.
- 16) The gymnasts were smiling at the trainer who helped their team.
- 17) The newspaper reporter phoned the secretary who was annoyed.
- 18) The handymen hated the factory machine that had been set on fire.
- 19) Susan carefully examined the pot's handle that she had repaired.
- 20) The grumpy inspector watched the policeman who was laughing.
- 21) The new neighbor spoke to the manager who was about to leave.
- 22) The female detective eyed the house entrance that was damaged.
- 23) The man admired the dollhouse furniture that had been repainted.
- 24) The Germans chose the agency's investments that made large profits.
- 25) The old producer talked to the guitarists who were good at singing.
- 26) The nurse in training trusted the patient who was leaving for home.
- 27) The teacher gave more work to the biology student who was upset.
- 28) The photographer enjoyed working with the model who was polite.
- 29) The girl in the pink dress envied the princess who just got engaged.
- 30) A pair of squirrels raced through the maple leaves that had fallen.

2.2 Non-restrictive RC condition

- 1) The inspector photographed the boat's cover, which was yellow.
- 2) The coach looked at the varsity players, who were very happy.
- 3) The picky journalist hated the soldiers, who were sitting down.
- 4) The clumsy plumber changed the sink faucet, which we installed.
- 5) My husband framed the certificate, which he received in the mail.
- 6) The article failed to mention the library, which had just been built.
- 7) The master looked at the innocent pupil, who was standing still.
- 8) The architect designed the water slide, which many children liked.
- 9) My uncle had to repair the bicycle tire, which my mom purchased.
- 10) My brother smashed the rental-agency's open car, which he hated.
- 11) The team leader showed us the bottle's label, which they designed.
- 12) The reporter interviewed the bodyguard, who looked handsome.
- 13) The lady from London disliked the player, who didn't say much.
- 14) The newspaper described the ceremony, which seemed very weird.
- 15) The early sun sparkled on the plane's propeller, which was broken.
- 16) The gymnasts were smiling at the trainer, who helped their team.
- 17) The newspaper reporter phoned the secretary, who was annoyed.

- 18) The handymen hated the factory machine, which had been set on fire.
- 19) Susan carefully examined the pot's handle, which she had repaired.
- 20) The grumpy inspector watched the policeman, who was laughing.
- 21) The new neighbor spoke to the manager, who was about to leave.
- 22) The female detective eyed the house entrance, which was damaged.
- 23) The man admired the dollhouse furniture, which had been repainted.
- 24) The Germans chose the agency's investments, which made large profits.
- 25) The old producer talked to the guitarists, who were good at singing.
- 26) The nurse in training trusted the patient, who was leaving for home.
- 27) The teacher gave more work to the biology student, who was upset.
- 28) The photographer enjoyed working with the model, who was polite.
- 29) The girl in the pink dress envied the princess, who just got engaged.
- 30) A pair of squirrels raced through the maple leaves, which had fallen.