A Closer Look: Investigating the Mechanisms of Syntactic Satiation

Monica Do and Elsi Kaiser

1. Introduction

Syntactic satiation is the phenomenon where *some* "sentences that were initially judged ungrammatical begin to sound increasingly acceptable" after repeated exposures (Snyder 2000, p. 575). However, despite the anecdotal prevalence of satiation among linguists, little is known about the mechanisms responsible for it. In fact, since Snyder's (2000) initial experiment, there remain a number of open questions: Whether satiation is linguistically driven, which structures can and cannot satiate, what factors influence satiation, how many exposures are necessary to induce satiation, etc.

Our study attempts to shed light on the mechanisms that might underlie satiation by using insights from a long attested and better understood phenomenon – *syntactic priming*. Like satiation, syntactic priming is exposure-based: Recent exposure to a certain syntactic structure facilitates subsequent processing of that structure (Bock 1986). Given this similarity, we believe that syntactic priming can help take initial steps into uncovering the mechanism(s) responsible for syntactic satiation.

We begin with an overview of recent work investigating syntactic satiation and syntactic priming. In section 2, we introduce our study, which builds on insights from syntactic priming to approach satiation in a new way. Our results, reported and discussed in sections 3 and 4, provide new evidence that Complex-NP Constraint (CNPC) and Subject islands are treated differently in the minds of comprehenders: We find that acceptability of CNPC islands is improved by a preceding CNPC island, but Subject islands show no such effects. Our results also show that the proximity of primes and targets affects ratings between prime and target sentences. In particular, we obtained significant effects of priming when primes and targets were separated by only one intervening sentence but less clear effects with five interveners. These results point towards a short-lived time course for satiation, suggesting that satiation may involve lingering activation of structural representations that decays over time.

1.1. Syntactic Satiation

In an initial experimental investigation, Snyder (2000) asked native English speakers to rate the grammaticality ('Yes' = grammatical/'No' = ungrammatical) of several types of *wh*-questions observed to be ungrammatical in English. Participants were asked to rate each question type a total of 5 times and, in order to determine whether there had been any improvement in participants' ratings of the ungrammatical sentences, Snyder (2000) compared the number of 'Yes' responses in the first two versus the last two exposures. More 'Yes' responses in the latter half indicated that participants' ratings for these ungrammatical sentences improved – i.e. *satiated* – as a result of the additional exposures.

Notably, Snyder (2000) found that while some ungrammatical sentence types showed evidence of satiation, others did not.[1] Since the initial study, though, research to date has been unable to replicate some of these original findings. For instance, though Snyder (2000) found significant effects of satiation among CNPC islands (1) and marginal effects of satiation among Subject islands (2), more recent experiments have shown irregular patterns of satiation for both island types.

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[1] Snyder (2000) tested 7 different question types. We focus here on only Subject and CNPC islands. Snyder also found satiation for *Whether*-islands; however, because they do not allow us to incorporate repetition type as a factor, we exclude them from the current study. Snyder did not find satiation in any other sentence types.

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(1) CNPC island: Who does Mary believe the claim that John likes (t)?

(2) Subject Island: What does John know that a bottle of (t) fell on the floor?
(Snyder 2000, pp. 276)

Specifically, while some experiments have found satiation effects for CNPC and Subject Islands, others have failed to replicate these satiation effects (Crawford 2012; Chaves and Dery 2014; see also Sprouse 2009 for review). Thus, one aim of the current study is to provide additional data that may help address an open empirical question regarding the status of CNPC and Subject islands.

Moreover, comparing the behavior of CNPC islands against Subject islands provides an additionally interesting contrast because of their statuses as 'weak' and 'strong' islands, respectively (Ross 1967; Chomsky, 1986).[2] For instance, given their 'weak' status and their variability cross-linguistically, CNPC islands have often been associated with processing-based factors (Kluender 1998; Hofmeister and Sag 2010; cf. Sprouse et al. 2012). By contrast, 'strong' islands like Subject islands have largely been accounted for in grammatical terms: Extraction out of Subject results in a Subjacency violation because the *wh*-phrase moves across two bounding nodes (Chomsky, 1986; Sprouse et al. 2012; cf. Kluender 2004). Although our study does not directly address which factors may influence satiability in one island type versus another (cf. Chaves & Dery 2014; Sag et al. 2007, inter alia), an asymmetric effect of satiation (e.g. a situation where satiation affects one island type but not the other) in the current study could shed light on a broader question posed by satiation – namely, the relationship between grammar and the processor. We do this by investigating satiation in terms of syntactic priming.

1.2. Syntactic Priming

Syntactic priming is the well-known phenomenon where exposure to a syntactic structure can facilitate subsequent processing of that same structure (Bock 1986). In general, priming effects have been attributed to two complementary (but not mutually exclusive) mechanisms: 1) Residual activation of a syntactic structure resulting in a short-lived priming effect (Pickering & Branigan 1998; Branigan et al 1999; etc.) and 2) Implicit learning of mappings between message-level representations and syntactic structures, resulting in a longer-term effect (Bock and Griffin 2000; Chang et al 2000; etc.).

Although the details of how these two mechanisms interact are still under debate, it is possible to distinguish between them by manipulating the number of intervening sentences between the prime and target sentences (Bock and Griffin 2000; Hartsuiker et al 2008). Specifically, residual activation accounts predict a short-lived priming effect; since activation decays over time, priming occurs when prime-target pairs are proximate, but not when they are further apart. By contrast, priming between distant prime-target pairs point to a more long-term priming mechanism due to implicit learning. Thus, manipulating the *proximity* between prime and target can shed light on the underlying mechanism.

Crucial to this study, an additional factor that can also influence priming is *lexical repetition* of a phrase critical to the syntactic structure (e.g. phrase heads). Specifically, when a prime and target sentence share lexical items, a short-term 'lexical boost' is often observed (Pickering & Branigan 1998; Cleland & Pickering 2003, etc.).[3]

2. Current Study

Given the parallels between syntactic satiation and syntactic priming, it may be possible that the underlying mechanism responsible for satiation may be related to priming. Our study departs from prior

[2] Ross (1967) identifies two classes of CNPC islands – ones created by extraction out of a relative clause and others via complement clause extraction. We focus on the latter, which is taken as a 'weak' island because of extraction crosses only one barrier (i.e. there is no Subjacency violation).

[3] Some suggest that lexical repetition of a phrase head may be required in comprehension priming. Results by Luka & Barsalou (2005) as well as Kaschak & Glenberg (2004) provide evidence to the contrary. These studies successfully primed moderately grammatical (e.g. 'I miss having time to do anything') and novel sentences (e.g. 'These vegetables need cooked'), respectively, without lexical repetition. Further, given that our study also manipulates lexical repetition of the island phrase itself, this issue is not central to the claims of this study.

satiation work, which compared acceptability judgments over the course of an entire experiment, i.e. looked at rating improvements on the 'global' level. Instead, we test for rating improvements between prime-target pairs – a 'local' level comparison – to see if recent exposure to an ungrammatical prime influences the acceptability of a subsequent ungrammatical target. Crucially, this allows us to manipulate factors known to influence syntactic priming – **(i) Proximity of exposure:** The number of unrelated sentences between the prime and target and **(ii) Lexical repetition:** The type of phrase repeated between the prime and target sentence – to tap into satiation effects that may have been previously undetected.

As we show below, our study found no effect of lexical repetition, but the proximity of prime and target sentences *did* play a role in inducing priming. When prime-target pairs were separated by one sentence (Lag1 group), we found an effect of priming in CNPC islands but not Subject islands. However, when prime-target pairs were separated by five sentences (Lag5), we find no priming for either island type. Our results suggest that what has been observed as syntactic satiation may be attributable to a short-term effect analogous to lingering activation decay of a recently processed structure.

2.1. Participants

Participants were recruited via Amazon Mechanical Turk. Six participants who reported a native language other than American English were excluded. We also excluded 11 participants who did not seem to pay attention to or understand the task (e.g. took abnormally long to complete the study, consistently rated grammatical fillers as 'Completely Unacceptable', responded incorrectly to more than 1 of 7 comprehension questions). The remaining 84 participants (n_{Lag1}=40, n_{Lag5}=44) were native native speakers of American English, age 18 years or older. Participants in the Lag1 group (79 items) were compensated $2 for participation. Participants in the Lag5 group (127 items) were compensated $3.

2.2. Materials and Procedure

The study was conducted over the internet using Qualtrics. Participants rate the acceptability of sentences using a five-point scale ranging from 1= "Completely Unacceptable" to 5= "Completely Acceptable". Participants were asked to complete the survey using a computer (i.e. no mobile or tablet devices) and to do so in one sitting, without interruptions. Each survey item was presented on a separate screen and backtracking was disabled. Participants were instructed to rate how "natural or unnatural" the sentences "intuitively" sounded to them. Prior to the survey portion of the experiment, they were also given an example and completed three practice sentences varying in acceptability.

To test the longevity of satiation, we created two versions of the study by varying (between-subjects) the number of sentences separating each prime from its subsequent target. Specifically, prime-target pairs were separated by either one (Lag1 group) or five (Lag5 group) unrelated, intervening sentences. In both versions of the study, participants rated 12 critical prime-target pairs (24 sentences) of two different sentence types: 6 CNPC islands, 6 Subject Islands (Table 1).

In addition, for each sentence type, we manipulated (within-subjects and within-items) whether the prime and target involved lexical repetition of (i) the island-forming DP that blocks *wh*-extraction (e.g. *claim* and *opponents* in Table 1) or (ii) a phrase unrelated to the island (the matrix verb in CNPC islands and adjunct expressions in Subject islands). Within each item, the target sentence was held constant while the prime sentence was manipulated to create the repetition conditions. This essentially created four different conditions, which we rotated via standard Latin Square design across four lists.

Depending on the version of the study, participants were also asked to rate the acceptability of 54-126 filler/intervener sentences which did not include any island-related violations. Since all critical sentences were ungrammatical, filler/intervener sentences included 6 additional sentence types (Table 2) ranging in complexity and acceptability. Thus, items in the study were balanced so that the number of ungrammatical sentences roughly equaled the number of grammatical sentences across the entire study. This design allowed us to minimize the risk of participants "giving up on" or attempting to equalize the number of responses during the study (Sprouse 2009). We also included 7 comprehension questions interspersed randomly throughout the study as catch trials.

Table 1 Sample critical items (primes and targets)

Sentence Type	Repetition Type	Trial Type	Example Sentences
CNPC	Island	Prime	Who did Richard dispute the claim that the paparazzi stalked?
		Target	Who did John deny the claim that the princess married?
	Unrelated	Prime	Who did Richard *deny* the allegation that the paparazzi stalked?
		Target	Who did John *deny* the claim that the princess married?
Subject	Island	Prime	What did opponents of hang a giant banner at the capitol?
		Target	What did opponents of start a violent riot outside the mall?
	Unrelated	Prime	What did fans of hang a giant banner *outside the mall*?
		Target	What did opponents of start a violent riot *outside the mall*?

Table 2 Sample *Ungrammatical* Filler/Intervener Items. Grammatical fillers of the following types were also included; however, we list here only ungrammatical filler/intervener items.

Filler Type	Example Sentence
Adjective Order	The waitress dropped the diamond gorgeous ring down the drain.
Agreement Attraction	The keys to the cabinet was rusty from years of disuse.
Case Assignment	Who helped they with the tax documents waiting to be filed?
Ellipsis	Rose will repaint the walls and Eve did so too the doors.
Telicity	Nick bragged that he worked on the speech in 3 days.
Wrong Preposition	What did the children bring of the playground?

2.3. Predictions

Most work in priming has largely focused on grammatical structures; but, recent work has shown priming in novel (Kaschak & Glenberg 2004) and moderately acceptable (Luka & Barsalou 2005) structures, indicating that priming is possible even with structures that initially seem unacceptable. If the priming also underlies the pattern currently known as 'satiation' (i.e., facilitation of ungrammatical sentences), then we should expect factors known to affect priming – lexical repetition and proximity of exposure – to affect satiation as well.

To test this, we looked at two different **Sentence Types**: CNPC islands and Subject islands. Given that CNPC islands are 'weak' islands known to be associated with processing-based effects, priming effects may be seen more straight-forwardly with CNPC islands than with Subject islands, which are 'strong' islands suggested to be a product of grammatical constraints impervious to processing.

Proximity of Exposure: Because activation decay and implicit learning accounts of priming are not mutually exclusive (Hartsuiker et al 2008, etc.), it is possible for satiation to be attributable to one or both of these mechanisms. If acceptability ratings from prime to target sentences improve (i.e. satiate) in the Lag1 version of the study, *but not* in the Lag5 version, this may point to satiation being a short-lived effect subject to decay over time. But, if ratings improve in *both* Lag1 and Lag5, this could point to satiation as a long-term effect analogous to implicit structure-learning.

Lexical Repetition: If satiation can be related to priming, we may also expect an increase in satiation when prime-target pairs share lexical items, in line with the lexical boost observed in structural priming. In particular, given its significance in the island structure, we may see stronger satiation effects when the head of the syntactic island is repeated than when phrases unrelated to the island are repeated. However, since lexical repetition is not required for syntactic priming (syntactic priming occurs without lexical repetition), our critical 'litmus test' is proximity of exposure.

3. Results and Discussion

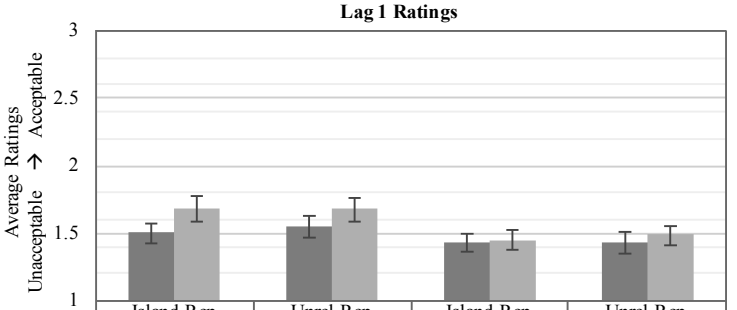
Sections 3.2 and 3.3 examine the patterns of priming in the Lag1 and Lag5 groups independently to determine whether acceptability ratings for CNPC or Subject island sentences are influenced by 1) Proximity of exposure: the number unrelated sentences separating primes and targets and 2) Lexical repetition: the type of phrase repeated between primes and targets. Section 3.4 compares the two groups.

3.1. Data Analysis

To control for individual variation in the rating scale, all statistical analyses were done on z-scores computed from each participants' mean response to all experimental items. (Statistical analyses using raw scores reveal the same basic pattern of results.) However, for ease of visual interpretation, graphs use the five-point rating scale.

Analyses were conducted in R using linear mixed-effects regression models. In the independent analyses of the Lag1 and Lag5 groups, we included sentence type (CNPC vs. Subject sentence), repetition type (Island vs. Unrelated repetition), and trial type (prime vs. target trial) as fixed-effects predictors. We also incorporated, as random effects, by-subjects and by-items adjustments to the slopes and intercepts. [4] Groups were also compared by reducing prime and target scores into a single difference score. For the difference score comparison, in addition to sentence type and repetition type, lag type (1 vs 5 intervening sentences) was also included as a fixed-effects predictor. Here, too, we incorporated by-subjects and by-items random-effects adjustments to the slope and intercept. Effects were judged to be significant if $|t| \geq 2$.

3.2. When one sentence intervenes between prime and target: Acceptability ratings for Lag1



	CNPC Island		Subject Island	
	Island Rep	Unrel Rep	Island Rep	Unrel Rep
prime	1.50	1.55	1.43	1.43
target	1.68	1.68	1.45	1.48

Figure 1: Lag1 Ratings. Error bars indicate +/- 1 SE. Scales ranged from 1='Completely Unacceptable' to 5='Completely Acceptable'. For visibility, we have condensed the scales here.

Figure 1 shows mean ratings for prime and target sentences in the Lag1 group, as a function of whether they are CNPC or Subject islands and whether the repetition involves the head of the island or an unrelated phrase. As can be seen in the figure, overall ratings for CNPC islands were higher than for Subject islands. Further, with CNPC islands, the ratings for target sentences (light gray) are higher than for primes (dark gray) regardless of repetition type, but this pattern is less clear with Subject islands.

Statistically, we found a significant effect of sentence type ($\beta = .09$, SE = .03, t = 2.82): CNPC islands were rated more acceptable than Subject islands. We also found a significant effect of trial type ($\beta = .05$, *SE* = .02, t = 2.3), but this was modulated by a marginal sentence type x trial type interaction ($\beta = .09$, *SE* = .05, t = 1.81). In other words, our results indicate that priming does not occur across the board: Target trials were significantly more acceptable than their prime counterparts in the case of CNPC islands ($\beta = .1$, *SE* = .04, t = 2.67), but not in the case of Subject islands ($\beta = .01$, *SE* = .03, t = .4).

For both CNPC and Subject islands, we found no significant effect of repetition type ($\beta = -.01$, *SE* = .02, t = -.41), indicating that lexically repeating the island itself versus a phrase unrelated to the island violation did not affect ratings. We found no significant interactions involving repetition type.

[4] We started with fully crossed and fully specified random effects then and reduced random effects starting with item effects (see Jaeger at http://hlplab.wordpress.com, May14, 2009). Then, we used model comparison to test each random effect; only models that converged were included in the comparison. Only random effects contributing significantly to the model were included. All models contained random slopes and intercepts for subjects and items.

3.3. When five sentences intervene between prime and target: Acceptability ratings for Lag5

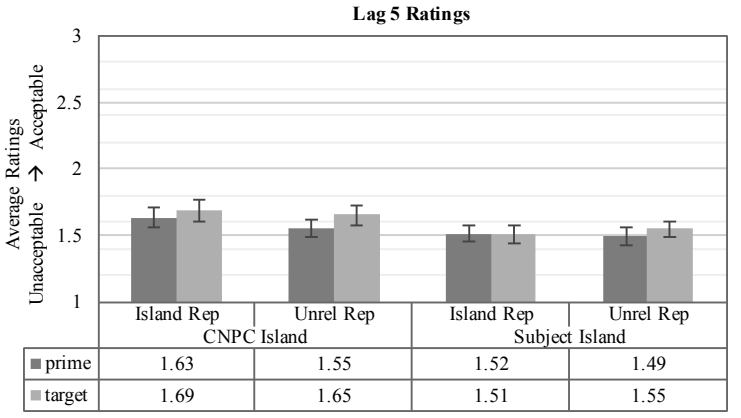


Figure 2: Lag5 Ratings. Error bars reflect +/- 1 standard error. Ratings range from 1-5.

Figure 2 shows mean ratings for prime and target sentences in the Lag5 group. CNPC islands again seem to be rated higher than Subject islands. However, when it comes to prime-target differences, we see only weak hints of target ratings being higher than prime ratings with CNPC islands, and essentially no prime-target differences with Subject islands.

Statistical analyses reveal a marginal effect of sentence type ($\beta = .08$, *SE* = .04, t = 1.91): CNPC islands were rated marginally more acceptable. Crucially, we found no effects of trial type ($\beta = .03$, *SE* = .02, t = 1.62): For both islands, ratings for target sentences were not significantly different than ratings for their corresponding primes. There were no interaction effects (all $|t| \leq 2$) and in particular, no sentence type x trial type interaction ($\beta = .04$, , *SE* = .05, t = .91). As in the Lag1 group, we also found no main effect or interactions with repetition type ($\beta = .01$, *SE* = .02, t = .58).

Our results indicate that when prime-target pairs are separated by five intervening sentences (Lag5), neither the CNPC nor the Subject island sentences show reliable signs of priming, in contrast to what we found for CNPC islands in the Lag1 group.

3.4. Comparing Lag1 to Lag5

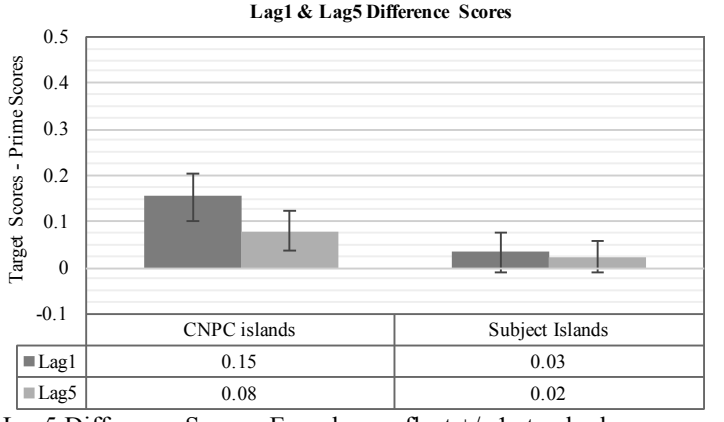


Figure 3: Lag1 & Lag5 Difference Scores. Error bars reflect +/- 1 standard error.

Although results from the independent analyses of the Lag1 and Lag5 groups already showed striking differences between the two groups, we also compared the Lag1 and Lag5 groups directly. To do this, we calculated difference scores for each prime-target pair by subtracting the prime rating from the target rating. A positive difference score signals an improved (higher) rating for the target than the prime. Our comparison showed a main effect of island type ($\beta = .06$, *SE* = .03, t = 2.14): Ratings for CNPC islands generally showed more improvement than for Subjects islands, in line with what we saw in Sections 3.2 and 3.3. Additionally**,** as can be seen in Figure 3, the difference scores for CNPC islands

are numerically larger for the Lag1 group than for the Lag5 group. However, a significant effect of lag size was not detected (β = .02, *SE* = .03, t = .63), which we suggest can probably be attributed to lack of power stemming from the between-subjects nature of the Lag1 vs. Lag5 design. As expected based on Sections 3.2 and 3.3, there are no effects of repetition (β = -.01, *SE* = .03, t = -.28) and no interactions.

4. General Discussion

The goal of this study was to understand satiation in terms of syntactic priming. If the phenomenon of syntactic priming also applies to the processing of ungrammatical sentences, then it may be possible to attribute 'satiation' to some form of syntactic priming. Moreover, if these two mechanisms – priming and satiation – are related, then factors known to affect priming, like proximity of a prime to its target and lexical repetition type, may affect sentences said to satiate similarly.

We explored this potential link in two distinct island types, CNPC and Subject islands, predicting that CNPC islands might be more susceptible to priming given prior claims that they are susceptible to processing effects in general. Prior work has proposed two complementary accounts of syntactic priming: *lingering activation* and *implicit learning*. We predicted that if satiation stems from rapidly decaying *lingering activation* of a recently encountered structure, then we expect priming only when prime and target sentences were proximate (here, separated by one sentence, Lag1). In contrast, if satiation stems from long-term *implicit learning*, then we expect to priming to occur even when prime and target sentences are further apart. Thus, priming could occur in both Lag1 and Lag5 groups. Finally, given that prior work has sometimes observed a 'boost' effect when prime and target share lexical items critical to the sentence structure, we hypothesized that repeating the head of an island might also 'boost' priming relative to repeating an unrelated phrase in the sentence.

4.1. Overall differences between CNPC islands and Subject islands

Work to date disagrees on CNPC vs. Subject islands: Some claim both satiate while others claim that neither or only one of these islands shows satiation effects. Our results reveal a clear difference between the two island types: Overall, CNPC islands were rated more acceptable than Subject islands and crucially, the acceptability of CNPC islands was improved by a preceding CNPC island (e.g. in Lag1), but Subject islands showed no such effects. This pattern of results was further corroborated by significantly higher ratings for CNPC islands than for Subject islands in the difference score comparison (and to a lesser extent, by a marginally significant difference in the Lag5 group).

Given that priming affected CNPC islands, our results provide initial evidence that it may be possible to link priming to satiation – at least in the case of CNPC islands. Subject islands, by contrast, do not seem to undergo priming, suggesting that what has been observed as satiation in these islands could be due to factors unrelated to priming. One possibility is that the underlying grammatical difference between 'weak' (CNPC) islands versus 'strong' (Subject) islands accounts for the pattern of results shown here: 'Weak' islands are claimed to be affected by processing-related factors while 'strong' islands are not. If so, this would suggest that a more appropriate characterization of satiation would attribute satiation effects in different island types to different factors. Another possibility could be that priming was possible in CNPC islands simply because these sentence types were 'licit enough' to induce priming and by extension, satiation. If this is the case, one way to explain conflicting prior experimental evidence about the status of CNPC and Subject island types could hinge on factors that influence the *initial* ratings these sentences receive (e.g. plausibility, see Chaves & Dery, 2014). Distinguishing between these options remains an open issue.

4.2. Priming effects when prime and target are close, no priming when they are far apart

We obtained significant effects of island type and trial type when primes and targets were separated only by one sentence (Lag1) but less clear effects when they were separated by five sentences (Lag5). In particular, participants rated CNPC islands (target) as significantly more acceptable when they had seen another CNPC island (prime) very recently. But, this effect was observed only when prime-target pairs were separated by one intervening sentence; when primes and targets were separated by five sentences, the priming effect was no longer detected. In contrast, Subject islands did not show priming effects at either lag. The sensitivity to the distance between prime-target pairs with CNPC islands points

towards a short-lived time course for satiation, akin to what lingering-activation accounts have proposed for the short-term effects in syntactic priming. Thus, our results provide initial evidence that short-term priming, involving the lingering activation of structural representations that decays over time, may be a contributing factor in what has been called satiation. This is not to say that satiation should simply be equated with priming – many questions remain open for investigation about the satiation phenomenon, but our current results point to some potentially common underlying mechanisms.

4.3. No boost from lexical overlap

In contrast to the lexical boost often observed with syntactic priming, we found no effects of 'repetition type' in our study: Participant's ratings of CNPC and Subject islands were not sensitive to whether the repetition is island-related or unrelated. Note, however, that because we did not compare the types of lexical repetition to a no-overlap baseline (i.e., where prime and target sentence have *no* lexically repeated content), care should be taken not to interpret these results as indication that there is *no* effect of lexical repetition on CNPC or Subject island priming. This issue merits further testing.

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