

ADAPTATION IN SYNTACTIC COMPREHENSION: A REPLICATION

BY

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THESIS

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Abstract

Language comprehension requires successfully navigating through a great degree of variability that is encountered on all linguistic levels. One hypothesis of how this variability is successfully dealt with is that listeners can rapidly update their statistical knowledge of how likely a linguistic event is to occur in a specific context. This process, called adaptation, allows listeners to better predict upcoming linguistic input. In previous work, Fine et al. (2013) designed an experiment to test for adaptation to uncommon syntactic structures. Subjects repeatedly encountered temporarily ambiguous RC/MV sentences. They found that subjects who had more exposure to the unexpected RC interpretation of the sentences had an easier time reading RC sentences but a harder time reading MV sentences. They concluded that syntactic adaptation occurs rapidly in unexpected structures and also results in trouble processing previously-expected, alternative structures. However, a power analysis revealed that Fine et al. (2013) ran an underpowered study. This thesis was designed to serve as a replication of Fine et al. (2013) with appropriate power. There was a failure to replicate Fine et al. (2013). The findings suggest instead that syntactic adaptation does not happen as rapidly as previously thought.

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Introduction

Successfully comprehending language requires that language users accommodate a wide range of variability in the linguistic signal. Variability occurs at every level of the linguistic signal, including phonological preferences, word choices, and syntactic preferences. Speakers vary in how they prefer to articulate sounds, which words they choose, and which syntactic structures they select. Adding to this difficulty, individual speaker's linguistic preferences are influenced by environmental factors such as background noise. How do listeners successfully understand language when the input is so variable? One proposal is that listeners adapt: they alter their expectations about the input based on past experiences and the current context (Fine et al., 2013; Kleinschmidt, Fine, and Jaeger, 2012; Kleinschmidt and Jaeger, 2015a; Kleinschmidt and Jaeger, 2015b; Xiang and Kuperberg, 2015; Norris, McQueen, and Cutler, 2016). Fine et al. (2013) conceptualize adaptation as “the processes that enable comprehenders to adjust linguistic expectations to a specific speaker or environment”. Recently, adaptation based theories have been used to explain syntactic processing effects (Jaeger and Snider, 2007; Fine et al., 2013; Fine and Jaeger, 2013; Kleinschmidt and Jaeger, 2015b). In this paper, we explore the limits of adaptation. To foreshadow the results of our experiment, which is a replication of Fine et al. (2013), we see little evidence of syntactic adaptation in processing reduced relative clauses. The goal of this paper is to understand constraints on syntactic adaptation as a means by which we can better understand the mechanisms that underlie it.

Much of the work on linguistic adaptation originates from the speech perception literature, demonstrating that listener's perception of the input changes with the statistics of the input (see Maye et al., 2002; Norris, McQueen, and Cutler, 2003; Kraljic and Samuel, 2007; Trude and Brown-Schmidt, 2011 just to name a few studies). On a broad scale, it is known that phoneme perception is affected by linguistic experience (Miyawaki et al., 1975; Trehub, 1976; Werker et al., 1981; Werker and Tees, 1984; Scott and Cutler, 1984). Adult speakers have difficulty perceiving contrastive phonemes that exist in other languages but not in their own (Miyawaki et al., 1975; Trehub, 1976; Werker et al., 1981). Infants, however, are able to perceive contrastive phonemes in languages other than their own until the age of ten months

(Werker and Tees, 1984). This developmental difference indicates that children quickly adapt to the linguistic signal.

Phoneme perception continues to be malleable after infancy (Scott and Cutler, 1984; Logan, Lively, and Pisoni, 1991; Bradlow et al., 1999; Bradlow and Bent, 2007). Scott and Cutler (1984) tested British-English speakers on their ability to hear phonetic contrasts that are commonly produced by American-English speakers but not by British-English speakers. They found that British-English speakers who lived in England had difficulty hearing these contrasts, but British-English speakers who had lived in the United States for several years were able to better hear the contrasts. Logan, Lively, and Pisoni (1991) showed that native Japanese speakers, who generally struggle to identify the r/l contrast, could improve r/l distinction after training. In a follow-up study, Bradlow et al. (1999) showed that this improved phonemic distinction is long-lasting. These studies show that phoneme categorization can change over the lifetime as a result of linguistic input. Recently, researchers have begun asking how quickly phonemic perception can change and if listeners can learn individual speakers' production patterns.

Norris, McQueen, and Cutler (2003) explored the sensitivity of phoneme perception listeners have to individual speakers. Native Dutch speakers completed a lexical decision task where they marked items as words or nonwords. The final fricative in 20 critical words was an ambiguous f/s sound that replaced the natural /f/ or /s/ in Dutch words such as "witlof" and "naaldbos". Subjects either heard only /f/ words or only /s/ words. After the lexical decision task, subjects completed a category identification task in which they heard multiple ambiguous f/s sounds on a continuum from /f/ to /s/. Each sound had to be categorized as either /f/ or /s/. Those who had heard the /f/ words in the lexical decision task were more likely to categorize ambiguous sounds as /f/. A similar pattern was observed for those in the /s/ group. This suggested that listeners used their lexical knowledge to restructure their understanding of the acoustic-phonetic properties of /f/ or /s/ to include the ambiguous f/s. This perceptual learning took place after only 20 critical trials which suggests that the speech perception can change rather rapidly.

Kraljic and Samuel (2007) investigated whether the perceptual learning demonstrated in Norris, McQueen, and Cutler (2003) could be maintained for more than one speaker at a time. English speaking subjects completed a lexical decision task and a category identification task

with an ambiguous /s/ phoneme. In both tasks subjects heard two speakers. One speaker produced /s/ in /f/ locations while the other produced /s/ in /s/ locations. In the category identification task, subjects who heard a voice in the /f/ condition during the lexical decision task were more likely to categorize /s/ phonemes as an /f/ for that same voice than the subjects who had heard the same voice in the /s/ condition. Kraljic and Samuel (2007) concluded that listeners were able to rapidly create and remember separate phoneme representations for /s/ for each speaker. The ability of the language system to do so indicates that perceptual learning is context-dependent and can depend on multiple cues.

Trude and Brown-Schmidt (2012) investigated whether listeners use their knowledge about speakers' phonetic productions to help predict incoming language. Subjects listened to speech from two talkers: a female speaker with a neutral accent and a male speaker who raised the /ae/ vowel to /ei/ before /g/. In an eye-tracking task, subjects were given instructions by both speakers to click on target pictures. Critical trials included target items that ended in -ack or -ake (as in "back" and "bake") and competitor items that ended in -ag (as in "bag"). The vowels in "bag" and "back" were the same for the unaccented speaker. The accented speaker produced "bag" and "bake" with the same vowel. The eye-tracking results showed that listeners used their knowledge of the speakers' vowel productions to begin predicting which item they were being asked to select before the instructions were completed. In trials with "back" and "bag", subjects were more likely to fixate on the target "back" for the accented speaker because "bag" was not a phonological competitor for the target item anymore. In trials with "bake" and "bag", subjects were less likely to fixate on "bake" when listening to the accented speaker because the items were phonological competitors. Trude and Brown-Schmidt (2012) concluded that listeners can alter their representation of speakers' vowel productions and then use these new representations to make rapid predictions regarding upcoming language. This line of work suggests that malleable speech perception allows listeners to more efficiently comprehend multiple speakers.

These data suggest that in speech perception, acoustic-phonetic categories are malleable even within the timeframe of an experiment. Subjects can modify their interpretation of a certain phoneme based on recent experiences. The fact that listeners are able to adapt to multiple listeners simultaneously suggests that the language system can nimbly and actively adapt to the current context. Thus, a question that researchers have posed in recent years is whether these

effects generalize to other aspects of language processing like syntax (e.g. Jaeger and Snider, 2007; Fine et al., 2013; Fine and Jaeger, 2013) and pragmatics (Degen and Tanenhaus, 2011; Yildirim et al., 2016).

The evidence for adaptation in parsing comes primarily from three types of findings in the literature: a) comprehenders are sensitive to the statistics of their linguistic environment b) this knowledge affects the language user's syntactic preferences in production and c) this knowledge has an immediate influence on parsing preferences. Below, we review well-established effects of frequency on language processing and effects of past syntactic exposure on speaker's current syntactic preferences (i.e. syntactic priming). Finally, we discuss the current evidence for comprehenders' use of local statistics to adjust expectations about syntactic structure.

Frequency Effects

One of the most important findings in language processing research over the last twenty-five years is that listeners and readers are sensitive to the frequency of syntactic structures, and this guides their parsing preferences (Trueswell and Tanenhaus, 1994; Trueswell, Tanenhaus, and Garnsey, 1994; Boland et al., 1995; Trueswell, 1996; Garnsey, 1997 and many others).

For example, Garnsey et al. (1997) showed that reading times in sentences that contain verbs that have ambiguous direct object and sentential complement continuations are affected by the frequency with which a verb appears with these structure. Subjects read sentences that were temporarily ambiguous as to whether they were a DO sentence or a SC sentence. Verbs in each critical sentence were either biased towards a DO verb, a SC verb, or were equibiased. Reading times were longer when the verb continuation was disambiguated towards the dispreferred structure. This work by Garnsey et al. (1997), as well as similar work by others (Trueswell and Tanenhaus, 1994; Trueswell, Tanenhaus, and Garnsey, 1994; Boland et al., 1995; Trueswell, 1996) show that syntactic preferences are sensitive to lexical and structural frequency. Readers have more difficulty processing low probability verb-structure pairings because they are unexpected. This suggests that language users track the statistics of the linguistic input and use them to guide comprehension.

Given that the language system is sensitive to the frequency of linguistic structures in the input, a reasonable hypothesis is that comprehenders might quickly update their parsing preferences based on the statistics of the immediate context. This is the central claim of syntactic adaptation, and there is at least some evidence for this in language production and comprehension, which we review in the next section

Syntactic Priming

After hearing or producing a given syntactic structure, speakers are more likely to produce that structure in the future (Bock, 1986; Bock, 1989; Potter and Lombardi, 1998; Pickering and Branigan, 1998; Kaschak and Glenberg, 2004; Thothathiri and Snedeker, 2007). Syntactic priming effects have been argued to demonstrate the presence of an abstract syntactic construction mechanism in production (Bock, 1986), as a mechanism for facilitating communication (Pickering & Garrod 2004), as a means of showing social solidarity (Niederhoffer and Pennebaker, 2002), as evidence for implicit learning (Chang, Dell, & Bock, 2006) and more recently, as evidence for syntactic adaptation (Fine & Jaeger, 2013).

Syntactic priming is seen as evidence for syntactic adaptation because of how rapidly it occurs. Because priming has been observed after exposure to single primes, it is evidence that the language system is immediately influenced by the appearance of a syntactic structure. This supports the claim that the language system is taking immediate context into account when making linguistic choices. Most syntactic priming research was designed to explore syntactic priming in production (Bock, 1986; Bock, 1989; Potter and Lombardi, 1998; Pickering and Branigan, 1998), but fairly recent evidence suggests that syntactic priming occurs during comprehension as well (Ledoux, Traxler, and Swaab, 2007; Thothathiri and Snedeker, 2008).

Thothathiri and Snedeker (2008) explored syntactic priming during spoken language comprehension. Subjects were shown four toys on a shelf in front of them. On each trial, subjects listened to short stories unrelated to the toys and then received instructions on what to do with the toys. On critical trials, the stories' last two sentences were either double object (DO) or prepositional object (PO) dative primes. A new speaker would then give instructions for the toys with either a DO or PO dative sentence that always asked subjects to move an inanimate theme to an animate recipient (e.g., DO: "Now you can send the horse the bottle"; PO: "Now you can send the horn to the frog"). The instructions were temporarily ambiguous up until partway

through the first noun phrase because the two target items (one animate and one inanimate) were always phonological competitors, such as “horse” and “horn”. Subjects could not know if the instruction was a DO or PO prime until the first noun phrase had been fully produced. Eye movements of subjects before they heard the complete first noun were analyzed to see if subjects were more likely to look towards the animal after hearing a DO prime.

Thothathiri and Snedeker (2008) found evidence that subjects’ comprehension was primed. After hearing DO primes, subjects were more likely to make predictive looks to the animate recipient after hearing “Now you can give the hor...”. This indicated that subjects were anticipating a DO structure of “Now you can give horse the object” after hearing a DO prime. The opposite pattern was observed in the PO-prime condition where subjects were more likely to make predictive looks to the inanimate theme, indicating that they anticipated “Now you can give the horn to the animal”. These eye movements are evidence that as subjects were primed by a syntactic structure, they anticipated that structure to occur in the instructions. This showed that hearing a syntactic structure immediately impacted the predictions the language system made about upcoming syntactic structures.

Syntactic priming effects provide evidence that the language system uses knowledge about the local frequency of syntactic structures to make comprehension and production decisions. Syntactic adaptation makes similar claims that parsing strategies are continuously updated based on which structures have occurred most frequently and recently in the system’s environment. In the next section, we discuss research which has explored the evidence for prior experiences influencing parsing strategies.

Syntactic Adaptation

Syntactic priming, frequency effects, and perceptual learning research all provide evidence for a malleable language system which can rapidly integrate new information into its understanding of the linguistic world. The parser is thought to behave similarly, resulting in syntactic adaptation. Below, we first discuss evidence that the comprehension system’s parsing strategies are based on more recent experiences with syntactic structures. We conclude the section with a review of Fine et al. (2013), the focus of our replication, which tests the specific predictions of syntactic adaptation.

The central claim of syntactic adaptation is that the parser maintains a distribution of recently experienced syntactic structures. If this is the case, when a comprehender encounters many structures of the same type in a short time period, reading speed should be reduced for the frequently experienced structure.

Wells et al. (2009) have provided preliminary evidence that supports this claim. The experiment was a series of reading tasks which tested the impact of increased exposure to infrequent grammatical structures. The critical structure type was relative clause sentences, which are typically difficult for subjects to read. Subjects in the experimental group read 160 relative clause sentences interspersed with fillers over the course of three to four weeks. The control group read the same amount of sentences but without relative clause sentences. Relative clause reading times for each subject were measured in a pre-test and post-test. At post-test, the experimental group read relative clauses significantly faster than they did at pre-test. The control group showed no such effect. Wells et al. (2009) concluded that the increased experience with relative clauses eased comprehension and reduced the reading speed associated with these sentences. This effect looks similar to the frequency effects (such as Garnsey et al., 1997) but on a shorter time scale. Subjects who learned that relative clauses were likely to occur could process them more easily than subjects who did not learn they were expected. Although this experiment spanned multiple weeks, it provided evidence that recent encounters with a syntactic structure are tracked by the parser.

In a similar experiment by Fine and Jaeger (2011), subjects read sentences with verbs that could take both sentence complement and direct object completions over the course of five experimental sessions. Subjects in the experimental group only saw sentences that ended in sentence complements, while the control group read sentences that ended in both sentence complements and direct objects. At post-test, the experimental group read temporarily ambiguous sentence complements faster than the control group. Fine and Jaeger (2011) argued that subjects tracked the occurrence of syntactic structures and continuously updated their estimates of how likely certain structures were to occur. All subjects were updating their distribution of how likely a verb was to be completed with a sentence complement or direct object complement. For the experimental group, the updated distribution informed them that

sentence complement endings were highly probable in the experimental context. This allowed the parser to ease comprehension by correctly predicting that this structure would be used.

The results of Wells et al. (2009) and Fine and Jaeger (2011) both showed that increased experience with a dispreferred structure improved reading ability later on. This suggests that the parser focuses on recently occurring syntactic structures when deciding on a processing strategy. Given these results, the next step for researchers was to explore if syntactic adaptation could happen within a shorter time period, similar to speech perception experiments.

As discussed before, syntactic priming is claimed to be a robust effect that is observed after minimal exposure to a syntactic structure. Fine and Jaeger (2013) analyzed Thothathiri and Snedeker's (2008) data to investigate the link between syntactic priming and syntactic adaptation. In a new experiment, Fine and Jaeger (2013) gave 171 participants the context story primes from Thothathiri and Snedeker (2008) in a sentence-completion norming task. Participants completed the prime sentences after reading the same context story which the subjects had heard in Thothathiri and Snedeker (2008). The sentence completions were coded as PO, DO, and other to provide a measure of how expected PO and DO structures were for each prime. This provided a measure of surprisal, how unexpected a structure was, for each prime. Fine and Jaeger (2013) then analyzed the eye-tracking data from Thothathiri and Snedeker (2008) in conjunction with the prime surprisal data collected for each item. The results showed that the higher the prime surprisal was for DO prime, the more likely it was that predictive looks would be made to the animate object that was consistent with a DO interpretation. The same pattern was seen for PO primes. This meant that as a structure became more unexpected, it was more likely to be predicted on the next target trial. Fine and Jaeger (2013) argued that this was evidence that the parser was driven by error-sensitive learning. The parser was sensitive to the size of prediction error which allowed it to quickly learn to change its parsing preferences when it made a large prediction error.

Fine and Jaeger (2013) concluded that Thothathiri and Snedeker's (2008) results were evidence of language users' expectations about upcoming input rapidly changing as a result of the error signal of the previous input. These results were viewed as evidence in support of syntactic adaptation where the parser eases comprehension by choosing its parsing preferences based on the frequency of recently occurring syntactic structures.

Kleinschmidt, Fine, and Jaeger (2012) proposed a Bayesian model to explain how syntactic adaptation might work. They proposed a language system which constantly tracks the distribution of linguistic events in its environment. This allows the language system to be aware of how often a linguistic event occurs, for instance knowing that relative clauses are a rare occurrence. This constantly changing distribution allows the language user to predict what syntactic structures are most likely to occur in a specific context. This probability of how likely a structure is to occur is based on many cues in the linguistic environment, such as what verb is present and if a complementizer is present, so that the system is predicting upcoming structures based on fine-grained information.

The Bayesian model predicts that giving subjects an unexpected structure gives them a greater opportunity to learn that this structure is now likely to occur. Because the language system is presumed to be error-sensitive, the strongest adaptation occurs when input is unexpected and predictions are wrong. This is what allows language users to rapidly learn to expect previously unexpected structures (as in Wells et al., 2009, and Fine and Jaeger, 2011). If syntactic adaptation occurs as this model predicts, it can be conceptualized as a rapid process that most strongly impacts syntactic structures that are not normally experienced. Next, we discuss the experiment which tested the predictions of this Bayesian model, and which will serve as the basis for our replication.

Syntactic adaptation claims that a) the parser continuously tracks the frequency of syntactic structures b) comprehenders use the recently updated frequency to predict which structure is occurring next and c) correctly predicting an upcoming structure results in facilitated comprehension (Fine et al., 2013; Kleinschmidt and Jaeger, 2015b).

In order to test the predictions of syntactic adaptation, Fine et al. (2013) designed a reading experiment which would explore whether syntactic adaptation could occur within one experimental session. Subjects were given a reading task where they read one sentence at a time. Critical sentences used verbs that could either be a main verb (MV) or a reduced relative clause (RC). Two example sentences are shown below.

1. A. The experienced soldiers warned of the danger before the midnight raid.
- B. The experienced soldiers warned of the danger conducted the midnight raid.

Sentence 1(A) is an easier sentence for most people to read. However, in 1(B) people tend to be garden-pathed upon reaching the word “conducted”. In both sentences, “warned” is initially parsed as the main verb of the sentence. In 1(A), this causes no problems as the reader is correct that it is the main verb. But in 1 (B) this analysis must be revised once the reader reaches the true main verb of the sentence – “conducted”. This difficulty in reading reduced relative clauses is thought to stem from its relatively lower likelihood compared to main verb readings. Analyses of corpora have shown that a temporarily ambiguous MV/RC sentence is far more likely to be completed as a MV than an RC (Fine et al., 2013).

Fine et al. (2013) made two predictions about these kinds of syntactic structures. The first is that increased exposure to RC sentences will make them easier to read. If syntactic beliefs are rapidly updated, increased exposure to RC sentences will tell the language system to expect more of these sentences, making them easier to read. The second prediction is that as exposure to RCs increase and exposure to MVs decrease, it will become harder to read MV sentences. Because the probability of encountering a MV decreases, the parser is no longer as ready to process this structure and experiences more difficulty when it encounters them.

Using reading times as the dependent measure, Fine et al. (2013) found that subjects with more exposure to RCs were able to read RCs more quickly. In addition, these subjects slowed down when reading MVs. These results are discussed in more detail below. Fine et al. (2013) concluded that adaptation occurs in syntactic processing and is seen even within the short time constraints of an experiment. Further, while adaptation helps the language system quickly process new or unexpected syntactic structures, it happens at the expense of alternative structures. In this case, reading many RCs meant that the alternative MV reading was less likely to occur and therefore more difficult for readers when they encounter it later. The conclusion was that the system had adapted to the input.

Our lab ran several experiments that were designed based on the results and conclusions of Fine et al. (2013). One line of research investigated whether adaptation can occur with respect to prosodic boundary placement (Harrington Stack, 2014). The other line of research investigated whether syntactic adaptation was affected by the context subjects were in as they encountered unexpected syntactic structures. Both lines of research failed to find evidence in support of adaptation. A power analysis of Fine et al. (2013) was run in order to understand how strong of

an effect adaptation might be. This power analysis revealed that Fine et al. (2013) was an underpowered study (Harrington Stack, James, and Watson, 2016). Because of this, we designed the experiment in this paper to serve as a replication of Fine et al. (2013) to test for syntactic adaptation. As discussed below, we failed to find evidence for syntactic adaptation.

Methods

Subjects

Fine et al. recruited 80 subjects from the University of Rochester. Subjects were paid \$10 for their participation.

Our replication recruited 481 American participants via Amazon Mechanical Turk. 58 participants were excluded due to experimenter error (i.e. posting the wrong consent form for the study). In total, the data for 423 subjects was analyzed. 210 subjects were in the experimental group, and 213 subjects were in the control group. Participants were paid \$4 for completing the experiment.

Materials

Fine et al. modified sentences from MacDonald et al. (1992). All critical sentences were either relative clauses (RC) or main verb (MV) sentences, as seen in 2 below. Half of all critical items were ambiguous, as in 2(A) and 2(C), where the verb *warned* was temporarily ambiguous as to whether the sentence would be resolved as an RC or a MV. The other half of the items were clearly disambiguated as an RC, as seen in 2(D), or as a MV, as seen in 2(B).

2. A. The experienced soldiers warned of the danger before the midnight raid.
- B. The experienced soldiers spoke about the dangers before the midnight raid.
- C. The experienced soldiers warned of the danger conducted the midnight raid.
- D. The experienced soldiers who were told about the dangers conducted the midnight raid.

In total, subjects read 71 sentences over three blocks. In blocks 1 and 2, subjects read only RC and filler items. In block 3, subjects read only MV and filler items. Verbs in the RC sentences in block 1 were unique. However, RC sentences in block 2 used a subset of block 1 RC verbs to create new items. Ambiguous MV sentences in block 3 repeated the same verbs used in block 2, but unambiguous MV sentences had entirely unique verbs. Filler sentences were created so that they did not contain verbs which had the RC/MV ambiguity.

The materials used in our replication were modified from Fine et al. (2013) as discussed below. In order to double the items to reach .95 power as indicated by the power analysis, we constructed additional new critical and filler items.

There were two important modifications made to the original Fine et al. materials. The first was to reduce the lexical overlap in both critical and filler items. As in Fine et al. (2013), critical items in block 2 and block 3 had repeated verbs from block 1, but most content-word repetition in the rest of the sentences was eliminated where possible. The second modification was that unambiguous RC items used the same verb as the ambiguous RC item, as in 3 (B) below. This was done so that the unambiguous condition more closely matched the ambiguous condition.

Critical items were either relative clause sentences, as shown in 3, or main verb sentences, as shown in 4. Half of the items were ambiguous and half were unambiguous. In 3(A) and 4(A), the sentence uses the same verb and is temporarily ambiguous as to whether the verb is being used as a relative clause or a main verb. In unambiguous relative clause sentences, such as 3(B), the relative clause was disambiguated by adding ‘who was’ before the verb. This differs from Fine et al. (2013) where yoked within item unambiguous RC items contained a different verb from the ambiguous conditions. Lastly, the verb in sentence 4(B) is an unambiguous main verb. Filler items were created that did not have the potential for an RC-MV ambiguity.

- 3. A. Several angry workers warned about low wages decided to file complaints.
- B. Several angry workers who were warned about low wages decided to file complaints.

- 4. A. The aging professors warned about the midterm just before fall break.
- B. The aging professors spoke about the midterm just before fall break.

Procedure

Fine et al. (2013) randomly assigned subjects to either the RC-first group or the Filler-first group. The experiment was split into three blocks, but from the perspective of the subject, it was one continuous experiment. Subjects in the RC-first group read 16 RCs in block 1, 10 RCs and 15 fillers in block 2, and 10 MVs and 10 fillers in block 3. Subjects in the Filler-first group read 16 fillers in block 1 and otherwise read identical blocks to the RC-first group.

Subjects read sentences in the lab in a word-by-word self-paced reading task. Each trial began with a series of dashes representing all non-space characters on the screen. Subjects were instructed to press the space bar in order to view each word. After a word was read, subjects moved to the next word, which would turn the prior word back into dashes. The duration between space bar presses was recorded. Each sentence was followed by a yes/no comprehension question where “yes” was the correct answer half of the time.

In our replication, the task was a word-by-word self-paced reading task hosted online on Ibex Farm. Participants read sentences one word at a time and moved onto the next word by pressing the spacebar. Words that weren’t currently being read were replaced by dashes. Reading time for each word was recorded. Each sentence was followed by a yes/no comprehension question where “yes” was the correct answer half of the time.

Prior to beginning the experiment, participants were given instructions on how to read the sentences by pressing the spacebar. They then received two practice sentences followed by two comprehension questions to ensure that they had practice with the experimental design.

The experiment was divided into three blocks, but from the participant’s viewpoint it was one continuous block. In total, participants read 144 sentences, including the two practice items. Participants were randomly assigned to one of four lists, two of which were the Filler-first conditions and two of which were the RC-first conditions. The RC-first group read 32 RC sentences in block 1. The Filler-first group read 32 filler items instead. Blocks 2 and 3 were identical for both groups. Block 2 consisted of 19 critical items that were relative clauses. 1 critical item in Block 2 was excluded from analysis due to experimenter error (a typo in the sentence). Block 2 also had 30 filler items. Block 3 consisted of 20 MV sentences and 20 fillers. Item order in lists was randomized while fulfilling the condition that there was at least one filler between critical items within each block.

Analysis and Results

Fine et al. (2013) completed three analyses to look for evidence of syntactic adaptation. These analyses were referred to as Questions 1, 2, and 3. Question 1 asked whether the ambiguity effect in Block 3, where critical items were MVs, was larger for the RC-First group than it was for the Filler-first group. Question 2 asked whether the ambiguity effect for the RC-First group was reduced from Block 1 to Block 2, where critical items were RCs. Question 3 asked whether the ambiguity effect in Block 2 for the RC-First group was reduced in comparison to the Filler-First group.

We present the same analyses in our replication for comparison. In each analysis, we will first discuss Fine et al.'s results in detail before presenting our own and discussing important differences.

For analysis, Fine et al. (2013) only included items that were answered correctly. Reading times below 100 ms and above 2000 ms were excluded from analysis. We excluded items based on the same criteria in our replication.

Both Fine et al. (2013) and our replication used length-corrected RTs as the dependent measure. This measure was obtained by regressing raw RT onto word length as well as including a by-subject random slope of letter count and random intercept for each subject. All analyses discussed below look at the disambiguating region of each sentence.

For the purpose of our analyses, we assumed that $p < .05$ when t -values were greater than 2 for any effect. The R package lme4 does not provide p -values for mixed-effects models. However, Baayen (2008, p. 266) indicates that determining the p -value based on the t -distribution is a valid strategy for large datasets.

Question 1 – Effect of adaptation on dispreferred structure

Question 1 asked whether the ambiguity effect in Block 3 was larger for the RC-first group than for the Filler-first group as predicted by adaptation accounts. A larger ambiguity effect for the RC-first group would suggest that increased experience with RCs early in the experiment resulted in difficulty reading MVs later. Importantly, other research has shown that

readers have an easier time reading MVs as compared to RCs (MacDonald, Just, and Carpenter, 1992). If it is the case that the RC-first group has increased difficulty with MVs, it would suggest that an *a priori* expected structure can become unexpected, and therefore more difficult to process.

Fine et al. (2013) regressed length-corrected RTs onto ambiguity, group, and the interaction between these variables. The maximal random effects justified by the data were included.

Fine et al. (2013) found a main effect of ambiguity ($\beta=8$, $p<.05$), where ambiguous MVs were read more slowly than unambiguous MVs. Fine et al. found no main effect of group ($\beta=4$, $p=.3$). Crucially, Fine et al. (2013) found a two-way interaction between ambiguity and group ($\beta=5$, $p<.05$). Subjects in the RC-first group showed a larger ambiguity effect for MVs than subjects in the Filler-first group. Fine et al. concluded that this was evidence that repeated exposure to RCs resulted in a processing cost to MVs that did not exist before.

Our replication ran the same analysis as Fine et al. (2013). There was no main effect of ambiguity in our replication ($\beta=.14$, $p > .05$). Subjects spent a similar amount of time reading ambiguous and unambiguous MV sentences. This was not surprising given that these were main verb sentences. Prior work has shown that main verb sentences are easier to read than relative clause sentences (MacDonald, Just, and Carpenter, 1992), and these data suggest that subjects continued to have little difficulty reading this sentence type. There was a main effect of group such that the RC-first group read both ambiguous and unambiguous sentences faster than the Filler-first group ($\beta=5.86$, $p < .05$). This effect of group may be somewhat explained by the RC-first group having more experience with the verbs repeated for ambiguous items. Crucially, we did not find the two-way interaction between ambiguity and group to be significant ($\beta= -.82$, $p > .05$). The ambiguity effect for MV sentences was not significantly different for the two groups. This indicates that the RC-First group was not having more difficulty reading ambiguous MV sentences as a result of their increased experience with RC sentences.

Subjects who had increased experience with RC sentences (51 sentences) did not have a harder time comprehending MV sentences than those subjects who had read only 19 RC sentences. We conclude that 51 exposures to an *a priori* unexpected structure does not negatively impact reading time of an alternative *a priori* expected structure.

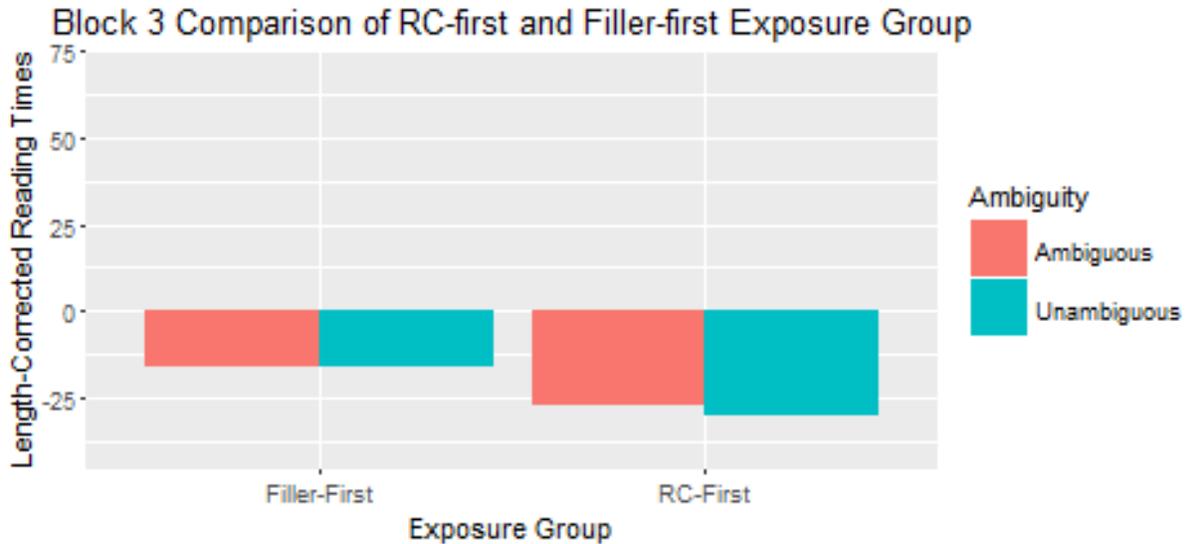


Figure 1

Question 2 – Comparison of ambiguity effect across blocks in experimental group

Question 2 asked whether the ambiguity effect was reduced from Block 1 to Block 2 for the RC-first group. If the ambiguity effect was reduced for the RC-first group, it would suggest that increased exposure to RCs resulted in an easier time processing this structure.

For this analysis, Fine et al. (2013) regressed length-corrected RTs onto ambiguity, block, and the two-way interaction between the two. The model also included the maximal random effects structure justified by the data.

Fine et al. (2013) found that there was a significant effect of ambiguity so that ambiguous RCs were read more slowly than unambiguous RCs ($\beta=20, p<.05$). There was also a significant main effect of block where subjects read the second block faster than the first block ($\beta=-63, p<.05$). Finally, they found that the interaction between these two (the ambiguity effect) was in the predicted direction but did not reach significance ($\beta=-9, p= .2$). Fine et al. (2013) argued that this lack of significance was most likely due to reduced power caused by grouping item order into two blocks, rather than looking at the items as a continuum of experience. To correct for this, a new analysis was run where length-corrected RTs during the disambiguating region were regressed onto ambiguity, item order, the interaction between ambiguity and item order, and the log stimulus order. The model also included the maximal random effects structure justified by

the data. Fine et al. (2013) found a main effect of ambiguity ($\beta = -.39$, $p < .05$) and log stimulus order ($\beta = -.176$, $p < .05$) to be significant. Crucially, they also found the two-way interaction between ambiguity and item order to be significant ($\beta = 2$, $p < .05$). They concluded that the ambiguity effect in block 2 was reduced for subjects in the RC-first group due to their increased experience with RC sentences.

Our replication ran an analysis similar to Fine et al. (2013) but it was necessary to exclude the by-subject random slope for ambiguity for the model to converge. There was a main effect of ambiguity where unambiguous sentences were read faster than ambiguous ones ($\beta = 5.735$, $p < .05$). This was expected as it replicated the garden-path effect seen in past research for RC sentences (MacDonald, Just, and Carpenter, 1992). There was also a main effect of block where subjects read sentences faster in block 2 as compared to block 1 ($\beta = -.69.55$, $p < .05$). This was expected as subjects gained experience with the task. However, the interaction of ambiguity and block did not reach significance meaning that the ambiguity effect was not smaller in block 2 than it was in block 1 ($\beta = -1.609$, $p > .05$). This indicated that the RC-first group was not able to read ambiguous RCs faster as a result of their increased experience with RCs.

We also analyzed the data to look at the ambiguity effect across individual items as Fine et al. (2013) did. We regressed length-corrected RTs onto ambiguity, item order, the interaction between the two, and log stimulus order. In this analysis, we found a main effect of ambiguity which indicated that ambiguous RCs were read more slowly than unambiguous one ($\beta = 8.84$, $p < .05$). There was also a main effect of item order suggesting that subjects were faster as they progressed through the task ($\beta = -2.85$, $p < .05$). However, log stimulus order did not reach significance ($\beta = 2.72$, $p > .05$). Ambiguity x item order did not reach significance either ($\beta = -.12$, $p > .05$). This indicated that the ambiguity effect for RC sentences was not significantly reduced as subjects gained more experience reading RC sentences.

Subjects did not have a decreased ambiguity effect as they moved from Block 1 to Block 2. There was also no evidence of a decreased ambiguity effect when looking at the data in terms of individual items rather than by block. We conclude that subjects did not significantly decrease their difficulty comprehending an *a priori* unexpected structure during 51 exposures to that structure.

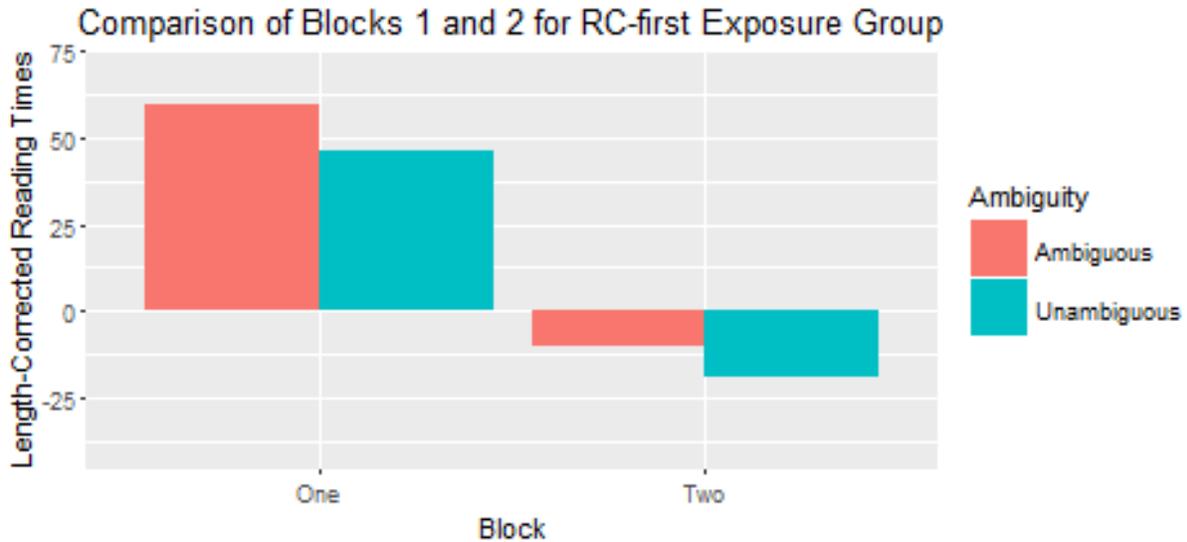


Figure 2

Question 3 – Comparison of ambiguity effect across groups in block 2

Question 3 asked whether the ambiguity effect in block 2 was greater for the Filler-first group than the RC-first group. If the Filler-first group had a larger ambiguity effect it would suggest that the RC group adapted more to RCs than the Filler-first group did due to having more exposure to the structure.

Fine et al. (2013) regressed length-corrected RTs onto ambiguity, group, and the interaction between the two. The model included the maximal random effects structure justified by the data.

Fine et al. (2013) found a main effect of ambiguity ($\beta=19$, $p<.05$) where unambiguous RCs were read faster than ambiguous RCs. There was also a main effect of group where subjects in the RC-first group had overall faster reading times ($\beta=-7$, $p<.05$). The two-way interaction between ambiguity and group was marginally significant in the expected direction ($\beta=-5$, $p=.08$). That is, the ambiguity effect in Block 2 was larger for the Filler-first group than for the RC-first group. This suggested that increased experience with RC sentences decreased processing difficulty for the RC-first group. Fine et al. (2013) argued that this was evidence that adaptation effects were caused by experience with RC structures.

Our replication ran a similar analysis to Fine et al. (2013), but the by-item random slope of ambiguity was excluded in order for the model to converge. We found a main effect of group where the RC-first group read both ambiguous and unambiguous sentences faster than the Filler-first group ($\beta=8.93$, $p < .05$). This could be explained by the RC-first group having already seen all the verbs that occurred in critical items in Block 1. There was also a main effect of ambiguity where unambiguous sentences were read faster than ambiguous sentences in both groups ($\beta=5.25$, $p < .05$). The crucial interaction between ambiguity and group was not significant ($\beta=.59$, $p > .05$). The ambiguity effect in Block 2 was not significantly different between the RC-first group and the Filler-first group. This indicated that subjects in the RC-first group were having similar difficulty processing RC sentences as the Filler-first group despite their increased experience with the structure.

Subjects who had increased experience with RC sentences did not have an easier time comprehending RC sentences than subjects who had only read RC subjects in Block 2. Along with our analysis of question 2, this data shows that 51 exposures to an *a priori* unexpected structure does not decrease the ambiguity effect associate with that *a priori* unexpected structure.

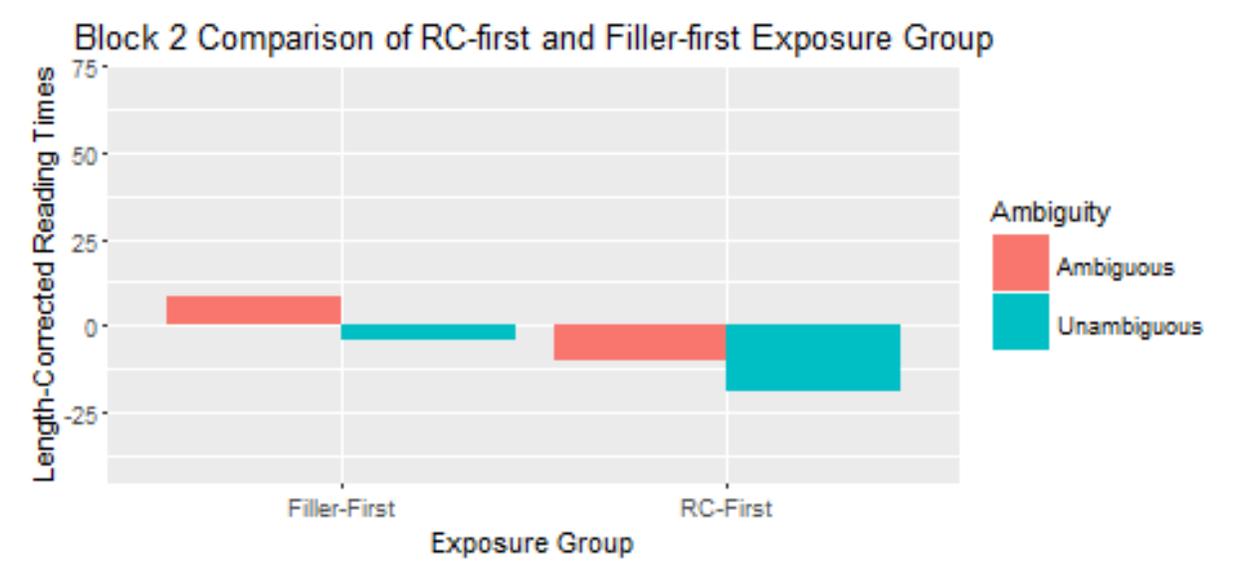


Figure 3

The results of all three analyses are summarized in the table . The table shows the β , t -value, and p -value in the disambiguating region for each of the analyses presented above. Significant entries are bolded.

<i>Predictor</i>	β	<i>t-value</i>	<i>p</i>
<i>Question 1</i>			
Ambiguity	.14	.110	>.05
Group	5.86	3.24	<.05
Ambiguity : Group	-.82	-.64	>.05
<i>Question 2</i>			
Ambiguity	5.74	2.16	<.05
Block	-69.55	-10.67	<.05
Ambiguity : Block	-1.61	-.29	>.05
<i>Question 3</i>			
Ambiguity	5.25	2.78	<.05
Group	8.93	4.45	<.05
Ambiguity : Group	.5925	.313	>.05

Table 1

General Discussion

Fine et al. (2013) presented data and analyses in support of syntactic adaptation to reduced relative clauses sentences. Fine et al. (2013) found that the ambiguity effect for RCs was significantly reduced after reading only 16 RC sentences. Further, they found that after reading 26 RC sentences, subjects had an increased ambiguity effect for formerly easy MV sentences. They concluded that readers rapidly infer the high probability of RC sentences occurring within the context of the experiment, which led to easier processing of RCs and more difficulty processing MV sentences. They concluded that this supports a theory of syntactic adaptation where comprehension of syntactic structures is impacted by the frequency of a syntactic structure occurring. This syntactic adaptation happens very quickly with effects being seen after only 16 exposures to RC structures. The result of facilitated comprehension for one structure is more difficulty in understanding alternative structures.

However, the data presented in this paper fail to support Fine et al.'s findings. A power analysis of Fine et al.'s (2013) raw data revealed that their experiment was underpowered (Harrington Stack, James, and Watson, 2016). Despite having 423 participants and 72 items in order to reach .95 power, this replication provided no evidence in support of syntactic adaptation.

There was not a significant reduction in the ambiguity effect for RC sentences for subjects in the RC-first group. Further, subjects in the RC-first group did not have any increased difficulty in reading MV sentences as a result of their exposure to RC sentences. Rather, our data show a trend of participants adapting to the reading task, and simply speeding up over the course of the experiment. Given the number of participants and items included in the replication, these null results are unlikely to be the result of Type II error.

Our results suggest that syntactic adaptation does not occur in MV/RC sentences. Over the course of 51 RC sentences, the RC-first group did not show a reduction in the ambiguity effect. Additionally, the RC-first group did not see an increased ambiguity effect in MV sentences as compared to the Filler-first group.

One concern in our study is that due to relatively large number of critical items, rapid adaptation effects might be hidden. That is, if syntactic adaptation is extremely fast, it may be happening at the very beginning of Block 1. These effects might be masked when we bin the

sentences into blocks. However, as part of our analysis of Question 2, we ran an analysis which looked at the significance of item order within blocks 1 and 2. Our analysis found that item order was significant, suggesting that subjects read faster as the task progressed. However, ambiguity x item order was not significant which suggests that the ambiguity effect was not reduced as subjects gained more experience with reduced relative clauses. Given the item order analysis presented in Question 2, we can be sure that the lack of adaptation is pervasive throughout the whole experiment both across blocks and across items.

Below, we discuss two conclusions that might be drawn from this lack of syntactic adaptation. The first is that syntactic adaptation occurs for other structures, but not in MV/RC structures, and the second is that syntactic adaptation does not occur across many or all syntactic structures.

At the very least, this failure to replicate Fine et al. (2013) provides evidence that syntactic adaptation does not occur in MV/RC ambiguities. Our experiment had enough items and participants to reach .95 power. It may be that we chose to test a structure in which adaptation simply doesn't occur. However, that doesn't seem likely. Many proponents of syntactic adaptation believe that the strongest adaptation occurs in unexpected structures (such as Kleinschmidt, Fine, and Jaeger, 2012). Because RCs occur so infrequently, we would expect to see particularly strong adaptation in this structure. If syntactic adaptation does work as proposed, there needs to be an explanation for why it did not work in the MV/RC structure.

However, this replication may be evidence of the larger claim that syntactic adaptation does not exist, at least not in the rapid way assumed by Fine et al. (2013) and others. We failed to find evidence of adaptation over the course of 52 relative clauses, which was far more than was presented in the original study. This was true both when the results were analyzed by block and by individual item order. This indicates that syntactic adaptation may not exist at all, at least not as rapidly as proposed. It seems more likely that syntactic adaptation exists, but on a slower time course than predicted by Fine et al. (2013). For instance, Wells et al. (2009) showed a reduced ambiguity effect for RC sentences after subjects came in for three to four weeks and read 160 RC sentences. This seems to be evidence for a system which does adapt and change, but requires significantly more evidence than theorized by Fine et al. (2013) to do so. How much evidence and time are needed in order to significantly change the language processing system is unclear.

This lack of syntactic adaptation in MV/RC sentences must be evaluated alongside other adaptation-related research to better understand the language processing system.

Prior Research

These results do not provide support for syntactic adaptation in MV/RR structures. Syntactic adaptation was originally proposed as a theory based on a large body of evidence that showed frequency effects, syntactic priming, and phoneme perception all displaying adaptation-like effects. Given the null results of this replication, we discuss below whether these known effects should be likened to syntactic adaptation.

Speech Perception

As stated before, syntactic adaptation theories originated from speech perception literature. Work in speech perception had shown that language users prior experience with ambiguous phonemes will change how they interpret those sounds (Norris, McQueen, and Cutler, 2003; Kraljic and Samuel, 2007; Trude and Brown-Schmidt, 2011). This work showed that the language processing system can rapidly adapt to new sounds being produced by a speaker.

Adaptation theories are built on this idea that phonetic perception is malleable even within the small timeframe of an experiment. When a subject hears a phoneme, they can modify their interpretation of it based on recent experiences. The fact that listeners are able to do this for multiple listeners simultaneously (Kraljic and Samuel, 2007) supports the idea of a language system that can quickly shift its interpretation of different contexts. This complements theories of adaptation which state that this adaptation is necessary for understanding a variety of different people with different linguistic outputs.

However, it is not immediately clear that syntactic comprehension should operate similarly to phoneme perception as seen in these experiments. An efficient speech perception system should be able to map specific sounds to specific speakers to deal with phoneme variation due to dialects, accents, and individual variation. Learning how each speaker produces these phonemes will allow a listener to successfully disambiguate words. Syntax, however, may be different because it does not necessarily follow a similar pattern. A speaker who produces main verb sentences always has the ability to produce a relative clause sentence at any time. Knowing

that a speaker or text has the ability to produce a variety of syntax may mean that the syntactic parser is less responsive to recent cues about a syntactic structure's frequency.

One last comment is that adaptation does not occur for all phonemes. Kraljic and Samuel (2007) found evidence for adaptation to multiple speakers to /s/ phonemes, but not to ambiguous d/t phonemes in the same experimental design. In the phoneme categorization task, it was found that subjects who heard two speakers producing ambiguous d/t phonemes would adjust only to the most recent speaker they heard. Kraljic and Samuel (2007) concluded that some phonemes, such as /d/ and /t/, do not provide speaker-specific acoustic information in the same way that /f/ and /s/ do. Even though adaptation occurs in speech perception, it is not consistent. This suggests that even in speech perception, there is variability in the extent to which linguistic elements elicit adaptation. Because all speakers have the ability to produce any syntactic structure at any time, the language system may not consider syntax to be a statistic that should be tracked to a specific speaker or context. It may suffice to track general frequencies of structures, but not rapidly adapt based on a singular context.

Frequency Effects

Frequency effects were also cited as evidence of adaptation-like effects in language. Prior work has shown that sentence reading is impacted by a verb's probability of occurring in a certain sentence type (Trueswell and Tanenhaus, 1994; Trueswell, Tanenhaus, and Garnsey, 1994; Boland et al., 1995; Trueswell, 1996; Garnsey, 1997). Sentence types that contained unlikely verbs had slower reading times. This work showed that syntactic processing is sensitive to lexical and structural frequency, and language users must be tracking the statistics of the linguistic input around them.

Theories of adaptation are based on the idea that frequency matters to processing. On a basic level, frequency effects show that statistics of some sort are being used by the language system. Syntactic adaptation theories argue however that these statistics can be rapidly updated. The Bayesian model shows that learning does not occur when frequent, expected structures occur. However, the model takes into account the frequency of uncertain structures and quickly updates its distributions based on what it experiences. Theories of adaptation argue that the recent frequency of a structure's occurrence is important for determining strength of adaptation, and determining how much the system will learn when it is wrong. In the case of Fine et al.

(2013), the linguistic system is thought to quickly notice the *a priori* unexpected structure, and then quickly learn that this structure is now likely to occur within the context of the experiment.

We argue that these frequency effects shown by Garnsey et al. (1997) are not the same as adaptation. While these studies offer evidence for a system which tracks the frequency of syntax, they only demonstrate the tracking of lifelong statistics. It is possible that the language system tracks the lifelong occurrence of structures without immediately updating as it encounters structures. If this is the case, the parser might require reaching a certain threshold of evidence before beginning to alter its distribution. Wells et al. (2009) and Fine and Jaeger (2011) showed that adaptation could occur after several experimental training sessions with dispreferred structures. This indicates that the parser may begin to alter its distribution after several days or after encountering a high number of unexpected structures. Taken together, these results provide evidence for a system which does track statistics, but not necessarily in the rapid manner proposed by Fine et al. (2013).

Syntactic Priming

Perhaps the most persuasive evidence in favor of syntactic adaptation is syntactic priming. Syntactic priming shows that speaker linguistic choice in production is rapidly influenced by surrounding linguistic input (Bock, 1986; Bock, 1989; Potter and Lombardi, 1998; Pickering and Branigan, 1998; Kaschak and Glenberg, 2004; Thothathiri and Snedeker, 2007). The repetition of a previously heard structure shows that the language system is sensitive to recently encountered syntactic structures. This effect happens immediately after exposure to a syntactic structure. This evidence is compatible with theories of adaptation which state that the language system is continuously adapting to the statistics around it.

Although syntactic priming appears to provide strong evidence in favor of syntactic adaptation, we argue a key difference. Simply, production and comprehension are not the same. Syntactic priming effects demonstrate a change in production that does not necessarily indicate a change in comprehension. Choosing to produce a DO sentence after hearing a DO prime may be more indicative of social entrainment. Entrainment is known to occur naturally between speakers. However, agreeing to use one form of linguistic communication does not mean that the speaker has trouble reverting to a previous form. For instance, Yoon and Brown-Schmidt (2014) showed that two partners could quickly entrain on a shortened reference for a tangram. If one of

the experienced partners is then placed with a new partner, they switch back to lengthy descriptions of the tangram. Here, the director is showing an ability to entrain with one speaker while also retaining the ability to switch descriptors when needed. This shows that the production system may choose to produce in a certain way based on the intended audience, but that does not mean that the comprehension system is confused by other options.

A further argument against syntactic adaptation may be found in Kaschak and Glenberg's (2004) results. In their experiments, subjects were exposed to a new 'needs' syntactic structure demonstrated by the sentence "The meal needs cooked" which has the same meaning as the sentence "The meal needs to be cooked". A subject who is unfamiliar with this construction will initially parse this sentence as needing a modifier such as "The meal needs cooked vegetables to make it complete". Similar to Fine et al. (2013), subjects were exposed to the new syntactic structure and then had their reading time measured for both the 'needs' construction and the alternative modifier construction. It was found that subjects were actually able to read the modifier sentences faster after exposure to the 'needs' construction. This is contrary to what syntactic adaptation predicts should happen where the alternative structure is now harder to comprehend. Kaschak and Glenberg (2004) concluded that the modifier construction was still being processed by the system as a potential interpretation parallel to the 'needs' construction. Switching back to a modifier sentence was not difficult because the processing system had continued to consider modifier constructions as a possibility.

However, Kaschak and Glenberg (2004) were able to induce syntactic adaptation like effects, where the initially preferred modifier interpretation was read slower, under specific conditions. If subjects received instruction on what the 'needs' construction was and how to interpret it before they began reading 'needs' sentences, their reading time on modifier sentences slowed down. Kaschak and Glenberg (2004) argued that this was support for the role of episodic processing in language comprehension. The episodic processing approach says that part of the memory of a stimulus is how that stimulus was processed. When subjects read the 'needs' construction with no instructions on how to process it, they would initially parse it as a modifier instruction. This makes the modifier interpretation part of the processing memory. When subjects were explicitly told how to interpret the 'needs' construction, they could process it without considering a modifier interpretation in parallel. This resulted in modifier interpretations no

longer being a part of the processing memory so that they were harder to process when they were encountered later.

The results of Kaschak and Glenberg (2004) demonstrate that exposure to a new structure does not necessarily result in a cost to the previously expected alternative structure. This adaptation-like effect can be induced when subjects are given explicit directions detailing how to interpret the syntactic structure. Giving explicit feedback to language users can alter the way in which different syntactic structures are processed though. This experiment suggests that improved comprehension of one syntactic structure does not naturally come at the cost of an alternative structure.

Syntactic Adaptation

Lastly, prior to Fine et al. (2013), Wells et al. (2009) and Fine and Jaeger (2011) had provided evidence in favor of syntactic adaptation. Both experiments had shown that increased exposure to a syntactic structure resulted in facilitation of comprehension of that structure. While this is evidence in favor of a flexible syntactic processor, these studies do not provide support for syntactic adaptation as defined by Fine et al. (2013).

Both Wells et al. (2009) and Fine and Jaeger (2011) looked at how comprehension of difficult structures changed as a result of increased exposure to that structure. Both experiments showed decreased reading speeds to difficult sentences after giving subjects lots of experience with the structure. The conclusions from these studies was that syntactic processing is flexible and is impacted by experiences with certain structures. These results seem to suggest syntactic adaptation occurs. However, it is important to note two differences between these studies and the ways in which syntactic adaptation is typically conceptualized.

There are two important aspects of proposed syntactic adaptation that we consider here. The first is the rapid nature of syntactic adaptation. Based on the analysis of syntactic priming by Fine and Jaeger (2013) and the Bayesian model proposed by Kleinschmidt, Fine, and Jaeger (2012), Fine et al. (2013) proposed that syntactic adaptation can occur in as little as 16 exposures to a structure. The timescale of Wells et al. (2009) and Fine and Jaeger (2011) do not allow for conclusions to be drawn about how rapidly adaptation occurs. Wells et al. (2009) had subjects come in over the course of three to four weeks, and Fine and Jaeger (2011) had subjects come to

three experimental sessions that were at least two days apart. These two experiments show that syntactic processing can change as a result of experience, but subjects need more experience than was provided in Fine et al. (2013) or our replication. The second important aspect of proposed syntactic adaptation is that easier processing of one structure results in difficulty processing an alternative structure. Neither Wells et al. nor Fine et al. analyzed the reading times of alternative structures in their experiments. These experiments then do not necessarily support the idea that syntactic adaptation will negatively impact the processing of some structures.

These studies that have looked at syntactic adaptation have demonstrated that there is evidence of a flexible syntactic parser, but they have not demonstrated that syntactic adaptation exists as proposed by Fine et al. (2013) exists. The results of their research combined with our failure to replicate Fine et al. (2013) suggests that a different view of syntactic adaptation should be taken.

Future Directions

Syntactic adaptation was proposed to explain how the parser successfully deals with variable syntax. Our failure to replicate the findings of Fine et al. (2013) serves as an argument against syntactic adaptation as it is currently conceptualized. Future work in this area should explore how the absence of syntactic adaptation in this paper helps to further define language processing in light of prior research demonstrating the flexibility of language processing.

The null results of this replication suggest that the theory of syntactic adaptation should be modified. At the very least, the failure to replicate shows that the parser does not immediately adapt to RC sentences. It seems likely though that these results may extend to more grammatical structures. If that is the case, syntactic adaptation should be conceptualized as a slower process that can happen over days or weeks, but not within a short experimental session. Further work should look at just how long this process of adaptation takes and what factors impact this.

Our null results also failed to show a negative impact on the comprehension of MVs. One possible explanation is that adaptation to a new structure does not have consequences for other structures. Prior research has shown that learning an entirely new syntactic structure does not result in difficulty processing an old alternative structure except under certain conditions (Kaschak & Glenberg, 2004). Further work could apply the methods of this work to already known syntactic structures. If it is possible to induce difficulty in reading MV sentences through explicit instruction on how to read RCs, it could serve as evidence that syntactic processing of a structure declines only under certain conditions.

Another possible explanation of our null results is that MV processing was not negatively impacted because the RC-First group did not have enough experience with RCs. The RC-First group did not show adaptation in this replication so a direct comparison cannot be made to the conclusions drawn by Fine et al. (2013) regarding the impact that adaptation had on MV sentences. Further work should ask whether adaptation to RCs over a longer timescale (as demonstrated in Wells et al., 2009) results in increased reading times of MVs.

Conclusions

Fine et al. (2013) proposed that syntactic adaptation, a rapid updating of the distributions of syntactic structures, was a natural part of language processing. They concluded that this syntactic adaptation resulted in easier comprehension of recently experienced structures and difficulty comprehending alternative structures. We designed a more powerful experiment similar to Fine et al. (2013) in an attempt to replicate these effects. We failed to replicate Fine et al. (2013). This indicates that syntactic adaptation does not happen as rapidly as thought and that alternative structures are not necessarily affected during the process. Prior work has shown that syntactic processing can be modulated by experience but more work must be done before conclusions can be drawn about how powerful adaptation is and how quickly it occurs.

References

- Baayen, R. H. (2008). *Analyzing Linguistic Data: A Practical Introduction to Statistics using R*. Cambridge University Press.
- Bock, J. K. (1986). Syntactic persistence in language production. *Cognitive psychology*, *18*(3), 355-387.
- Bock, J. K. (1989). Closed-class immanence in sentence production. *Cognition*, *31*(2), 163-186.
- Boland, J. E., Tanenhaus, M. K., Garnsey, S. M., & Carlson, G. N. (1995). Verb argument structure in parsing and interpretation: Evidence from wh-questions. *Journal of Memory and Language*, *34*(6), 774.
- Bradlow, A. R., Akahane-Yamada, R., Pisoni, D. B., & Tohkura, Y. I. (1999). Training Japanese listeners to identify English/r/and/l: Long-term retention of learning in perception and production. *Perception & psychophysics*, *61*(5), 977-985.
- Bradlow, A. R., & Bent, T. (2008). Perceptual adaptation to non-native speech. *Cognition*, *106*(2), 707-729.
- Chang, F., Dell, G. S., & Bock, K. (2006). Becoming syntactic. *Psychological review*, *113*(2), 234.
- Degen, J., & Tanenhaus, M. K. (2011). Making inferences: the case of scalar implicature processing. In *Proceedings of the 33rd annual conference of the cognitive science society* (pp. 3299-3304). Austin, TX: Cognitive Science Society.
- Fine, A. B., Jaeger, T. F., Farmer, T. A., & Qian, T. (2013). Rapid expectation adaptation during syntactic comprehension. *PloS one*, *8*(10), e77661.
- Fine, A. B., & Jaeger, T. F. (2011, July). Language comprehension is sensitive to changes in the reliability of lexical cues. In *Proceedings of the 33rd annual meeting of the Cognitive Science Society* (pp. 925-930).
- Fine, A. B., & Jaeger, T. F. (2013). Evidence for implicit learning in syntactic comprehension. *Cognitive Science*, *37*(3), 578-591.
- Garnsey, S. M., Pearlmutter, N. J., Myers, E., & Lotocky, M. A. (1997). The contributions of verb bias and plausibility to the comprehension of temporarily ambiguous sentences. *Journal of Memory and Language*, *37*(1), 58-93.
- Harrington Stack, C. (2014). Adaptation in Intonational Boundary Placement. Presented at *Cognitive Psychology Brownbag, University of Illinois at Urbana-Champaign*.
- Harrington Stack, C., James, A., & Watson, D.G. (2016). Syntactic Adaptation: A Replication. *Unpublished Manuscript in Preparation*

- Jaeger, T. F., & Snider, N. (2008). Implicit learning and syntactic persistence: Surprisal and cumulativity. In *Proceedings of the 30th annual conference of the cognitive science society* (pp. 1061-1066).
- Kaschak, M. P., & Glenberg, A. M. (2004). This construction needs learned. *Journal of Experimental Psychology: General*, *133*(3), 450.
- Kleinschmidt, D., Fine, A. B., & Jaeger, T. F. (2012). A belief-updating model of adaptation and cue combination in syntactic comprehension. In *Proceedings of the 34rd Annual Meeting of the Cognitive Science Society (CogSci12)* (pp. 605-10).
- Kleinschmidt, D. F., & Jaeger, T. F. (2015a). Re-examining selective adaptation: Fatiguing feature detectors, or distributional learning?. *Psychonomic bulletin & review*, 1-14.
- Kleinschmidt, D. F., & Jaeger, T. F. (2015b). Robust speech perception: recognize the familiar, generalize to the similar, and adapt to the novel. *Psychological Review*, *122*(2), 148.
- Kraljic, T., & Samuel, A. G. (2007). Perceptual adjustments to multiple speakers. *Journal of Memory and Language*, *56*(1), 1-15.
- Ledoux, K., Traxler, M. J., & Swaab, T. Y. (2007). Syntactic Priming in Comprehension: Evidence from Event-Related Potentials. *Psychological science*, *18*(2), 135-143.
- Logan, J. S., Lively, S. E., & Pisoni, D. B. (1991). Training Japanese listeners to identify English/r/and/l: A first report. *The Journal of the Acoustical Society of America*, *89*(2), 874-886.
- Maye, J., Werker, J. F., & Gerken, L. (2002). Infant sensitivity to distributional information can affect phonetic discrimination. *Cognition*, *82*(3), B101-B111.
- Miyawaki, K., Jenkins, J. J., Strange, W., Liberman, A. M., Verbrugge, R., & Fujimura, O. (1975). An effect of linguistic experience: The discrimination of [r] and [l] by native speakers of Japanese and English. *Perception & Psychophysics*, *18*(5), 331-340.
- Niederhoffer, K. G., & Pennebaker, J. W. (2002). Linguistic style matching in social interaction. *Journal of Language and Social Psychology*, *21*(4), 337-360.
- Norris, D., McQueen, J. M., & Cutler, A. (2003). Perceptual learning in speech. *Cognitive psychology*, *47*(2), 204-238.
- Norris, D., McQueen, J. M., & Cutler, A. (2016). Prediction, Bayesian inference and feedback in speech recognition. *Language, cognition and neuroscience*, *31*(1), 4-18.
- Pickering, M. J., & Branigan, H. P. (1998). The representation of verbs: Evidence from syntactic priming in language production. *Journal of Memory and language*, *39*(4), 633-651.
- Pickering, M. J., & Garrod, S. (2004). Toward a mechanistic psychology of dialogue. *Behavioral and brain sciences*, *27*(02), 169-190.

- Potter, M. C., & Lombardi, L. (1998). Syntactic priming in immediate recall of sentences. *Journal of Memory and Language*, 38(3), 265-282.
- Scott, D. R., & Cutler, A. (1984). Segmental phonology and the perception of syntactic structure. *Journal of Verbal Learning and Verbal Behavior*, 23(4), 450-466.
- Thothathiri, M., & Snedeker, J. (2008). Give and take: Syntactic priming during spoken language comprehension. *Cognition*, 108(1), 51-68.
- Trehub, S. E. (1976). The discrimination of foreign speech contrasts by infants and adults. *Child development*, 466-472.
- Trude, A. M., & Brown-Schmidt, S. (2012). Talker-specific perceptual adaptation during online speech perception. *Language and Cognitive Processes*, 27(7-8), 979-1001.
- Trueswell, J. C. (1996). The role of lexical frequency in syntactic ambiguity resolution. *Journal of memory and language*, 35(4), 566-585.
- Trueswell, J. C., & Tanenhaus, M. K. (1994). Toward a lexicalist framework for constraint-based syntactic ambiguity resolution.
- Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). Semantic influences on parsing: Use of thematic role information in syntactic ambiguity resolution. *Journal of memory and language*, 33(3), 285.
- Wells, J. B., Christiansen, M. H., Race, D. S., Acheson, D. J., & MacDonald, M. C. (2009). Experience and sentence processing: Statistical learning and relative clause comprehension. *Cognitive psychology*, 58(2), 250-271.
- Werker, J. F., Gilbert, J. H., Humphrey, K., & Tees, R. C. (1981). Developmental aspects of cross-language speech perception. *Child development*, 349-355.
- Werker, J. F., & Tees, R. C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant behavior and development*, 7(1), 49-63.
- Xiang, M., & Kuperberg, G. (2015). Reversing expectations during discourse comprehension. *Language, cognition and neuroscience*, 30(6), 648-672.
- Yildirim, I., Degen, J., Tanenhaus, M. K., & Jaeger, T. F. (2016). Talker-specificity and adaptation in quantifier interpretation. *Journal of memory and language*, 87, 128-143.
- Yoon, S. O., & Brown-Schmidt, S. (2014). Adjusting conceptual pacts in three-party conversation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40(4), 919.