INVESTIGATING THE ROLE OF DISTRIBUTION IN SYNTACTIC COMPREHENSION

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ABSTRACT

Valerie Johanne Langlois: Investigating the role of distribution in syntactic comprehension
(Under the direction of Jennifer Arnold)

Comprehenders encounter a variety of syntactic structures through reading or spoken conversation. In some cases, sentences can be ambiguous and have more than one meaning. In *The spy saw the cop with the binoculars*, one interpretation is that the spy is looking through the binoculars, while an alternative is that the cop has the binoculars. Despite this ambiguity, comprehenders are able to converge on a single interpretation. The mechanisms behind this are still debated today as many factors have been shown to guide comprehension. Experience is thought to play a large role in comprehension, yet despite its large role in theoretical models, there is still no direct evidence of whether people actually keep track of distribution i.e., the relative frequency of a target structure and its competing structures.

In three self-paced reading experiments, the current study investigates whether people can implicitly acquire syntactic distributional information given the verb *needs*, and whether that information can be generalized to another verb. In all experiments, the relative frequency of an unfamiliar, dialectal structure (*The meal needs cooked*) was manipulated while holding raw frequency constant, resulting in the creation of different syntactic distributions. Results showed differences in syntactic processing in a distribution with a high proportion of the dialectal structure compared to one with a low proportion of the dialectal structure (Exp. 1). However, there were no differences in processing when the dialectal structure was the majority (Exp. 2).

Furthermore, relative frequency information did not transfer to a new verb that used the same syntactic structure (Exp. 3). This study is the first to show causal evidence of comprehenders acquiring relative frequency information, consistent with current models of syntactic processing. Further research will need to address open questions about the level of statistical detail acquired, and what kind of information is generalized.

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CHAPTER 1: INTRODUCTION

Comprehenders encounter a variety of syntactic structures in everyday life, whether through reading or spoken conversation. Some structures are more common than others. For example, people are less likely to hear sentences such as *The soldiers warned about the dangers conducted the raid* where the verb *warned* modifies *the soldiers* (relative clause), compared to when *warned* is used as a main verb e.g. *The soldiers warned about the dangers before the raid.* The verb *warned* has a higher probability of being used as a main verb compared to being embedded in a relative clause. This creates a distribution where one structure is more frequent relative to the other, given the verb *warned*.

Differences in relative frequency have led to claims about how experience with the distribution of syntactic structures influences comprehension. Infrequent structures such as relative clauses impose more processing difficulty as measured by reading time (MacDonald, Pearlmutter, & Seidenberg, 1994). Experience with these structures decreases this difficulty (Fine, Jaeger, Farmer, & Qian, 2013; Wells, Christiansen, Race, Acheson, & MacDonald, 2009), which implies a process of learning through exposure. However, it is unclear whether overall *raw* frequency or *relative* frequency of a structure is leading to decreases in processing difficulty. In addition, the effect of distribution on processing has only been investigated by correlating data from corpora and reading times (e.g. Gennari & MacDonald, 2009). Therefore, despite the emphasis of relative frequency in theoretical models, we do not have direct evidence of whether comprehenders actually keep track of distribution.

The current study investigates whether comprehenders can implicitly acquire syntactic distributional information by directly manipulating the relative frequency of syntactic structures i.e. the probability of a structure occurring relative to other competing structures. Experience-based models of syntactic comprehension (e.g. Gennari & MacDonald, 2009; Jurafsky, 1996; Levy, 2008; MacDonald et al., 1994) predict that more frequent structures are easier to process, and experience with these structures results in higher expectations for a particular syntactic parse. For example, if introduced to an unfamiliar structure e.g. *The meal needs cooked,* comprehenders may initially have to slow down due to difficulty processing the unfamiliar sentence structure. However, if comprehenders implicitly keep track of the relative frequency of the novel structure and other structures that use the verb *needs* (e.g. *The meal needs cooked vegetables*) given the input beforehand, then a distribution with a relatively higher proportion of the novel structure should make processing easier. In other words, these models claim that when given constraining input such as *The meal needs cooked,* comprehenders learn to expect the novel structure due to its high probability relative to its competitors. This facilitation occurs over and above its raw frequency.

Testing the role of distribution is relevant both for general theories of statistical learning and theories of syntactic comprehension. People can use statistical information in the linguistic input to learn different aspects of language (e.g. Saffran, Newport, & Aslin, 1996), and this mechanism plays a central role in connectionist models of language acquisition (e.g. Bates & MacWhinney, 1987; Elman, 1990). Therefore, evidence that statistical patterns influence acquisition can point to expected statistical patterns in comprehension. More specifically, distributional information is directly relevant to experience-based models of syntactic comprehension. This class of models critically argues that the relative frequency of a syntactic

structure matters and not just the overall raw frequency; comprehenders are sensitive to the probability of which a structure occurs *relative* to alternate structures, e.g. the probability of the verb *warned* occurring in a relative clause vs. as the main verb. However, this claim has not been adequately tested.

The current study directly manipulates the relative frequency of two different competing syntactic structures: the dialectal *needs* structure (*The meal needs cooked*, a variation of *The meal needs to be cooked*) and the modifier structure (*The meal needs cooked vegetables*). The *needs* + past participle structure is from a variety of English most closely affiliated with Western Pennsylvania (Murray, Frazer, & Simon, 1996). The current project uses this dialectal structure as a test case, as most people outside of the Western PA region are relatively unfamiliar with the dialectal *needs* structure. Variation in the linguistic environment stems from a number of sources, such as dialect, age, and gender, (Finegan & Biber, 2009; Tagliamonte & Smith, 2005; Weiner & Labov, 1983), all of which contribute to the variability people encounter on a daily basis. In addition, the distribution of syntactic structures depends on whether the corpora are spoken or written (Roland, Dick, & Elman, 2007). Since variability in experience leads to individual differences in processing (MacDonald & Christiansen, 2002; Wells et al., 2009), the use of the dialectal *needs* structure allows for more control over linguistic variability. This provides a baseline for experience, as the dialectal structure is fairly uncommon for most speakers. Despite this unfamiliarity, comprehenders can rapidly adapt to the dialectal *needs* structure with enough exposure (Fraundorf & Jaeger, 2016; Kaschak & Glenberg, 2004).

Both the dialectal and modifier structures are syntactically ambiguous until two words after *needs,* allowing for competition between the two structures. Unlike previous studies, this project controls the overall amount of exposure (i.e. raw frequency) to the dialectal structure

within the experiment while manipulating the distribution, i.e. the relative probability of the dialectal and modifier structures occurring with *needs*. This way, any reduction in processing difficulty can be attributed to the new distribution, rather than overall exposure to the dialectal structure.

Experience-based models imply implicit distributional knowledge

Several different theories of syntactic processing rely on exposure to statistical regularities in the linguistic input to explain how comprehenders process the meaning of a sentence as it unfolds. Experience-based models each propose slightly different mechanisms for the role of experience. For example, constraint-based approaches to syntactic comprehension argue that the initial interpretation of a sentence is constrained by the relative frequencies with which a word co-occurs with different syntactic structures (MacDonald et al., 1994; Tanenhaus & Trueswell, 1995; Trueswell, 1996). These accounts propose that multiple alternative interpretations are activated in parallel and are available to the comprehender, and constraints such as contextual and frequency information guide comprehension. Under this approach, infrequent structures are more difficult to process due to less activation, and therefore cannot compete against more frequent structures.

Probabilistic models (e.g. Hale, 2001; Jurafsky, 1996; Levy, 2008) put more emphasis on probability theory compared to constraint-based approaches. Processing difficulty occurs when the highly probable structures are expected by the comprehender but not encountered, which then leads to reanalysis (Jurafsky, 1996). Other theories reframe this same idea in terms of *surprisal*, i.e. a measure of how unexpected the input is to the comprehender. Levy (2008) proposed a resource allocation theory framed in terms of parallel processing, where difficulty of a new word depends on its surprisal. In his model, surprisal is defined as the reallocated resources needed to

replace the old distribution of syntactic structures with new information based on new parses. As the sentence unfolds, with each new word, the surprisal of the next word either increases or decreases. In *The soldiers warned…* comprehenders expect the upcoming word to be a noun, based on their distribution of syntactic parses. However, if the next word encountered is *about*, comprehenders must reallocate resources to re-update their distribution, resulting in a slowdown in processing. As a result, this affects expectations; comprehenders implicitly update their expectations about the upcoming structure and/or word given the previous input.

The key idea in experience-based models is that comprehenders are sensitive to the relative frequencies of competing structures, not just the overall frequency of a structure. However, the primary type of evidence used to support this idea comes from correlations between the frequency of structures and ease of processing. One type of correlational claim relies on the frequency of a structure associated with a verb. For example, the verb *warned* usually is not embedded in a relative clause (*The soldiers warned about the dangers conducted the raid*), and is used more frequently used as a main verb *(The soldiers warned about the dangers before the raid*). Since this verb-structure co-occurrence results in processing difficulty, this has led to the claim that the verb *warned* embedded in a relative clause structure is harder to process because it is infrequent compared to when it is used as a main verb (MacDonald, 1994; Trueswell, 1996).

A second correlational argument is that people are sensitive to syntactic probabilities that are contingent on factors such as animacy and verb type (Gennari & MacDonald, 2008; 2009; MacDonald & Thornton, 2009; Mak, Vonk, & Schriefers, 2002). For example, consider the sentence *The director that the movie pleased had received a prize* in comparison to *The movie that the director watched had received a prize.* Despite the fact that both sentences have the

same syntactic structure, comprehenders have more difficulty with the former due to the animacy of the head noun (*the director*) and the verb *pleased.* Verbs like *pleased* tend to occur in passive relative clauses (*The director that was pleased by the movie*) rather than in active relative clauses. In addition, processing of relative clauses is affected by the animacy of the head noun, with inanimate head nouns (e.g. *the movie*) being easier to process in object relative clauses compared to animate head nouns (e.g. *the director*). The effect of animacy lines up with findings from corpora; object relative clauses with inanimate head nouns are more frequent relative to clauses with animate head nouns (Roland et al., 2007; Mak, Vonk, & Schriefers, 2002). Therefore, comprehenders are relatively unlikely to hear the sentence *The director that the movie pleased had received a prize,* and this correlates with comprehension difficulty. In contrast, *The movie that the director watched had received a prize* is processed with less difficulty, despite having the same syntactic structure (Gennari & MacDonald, 2008). These findings are used to support the claim that comprehenders can keep track of very fine-grained distributional information, and by extension also show support for experience-based models.

Changes in distribution should elicit a change in comprehension

Though correlational work supports experience-based models, better evidence for comprehenders learning distributional patterns can come from directly manipulating the linguistic input. Experience-based models claim that experience with the distribution of syntactic structures shapes how comprehenders parse the sentence. As a consequence, these models predict that changes to the distribution will affect comprehension. Computational simulations have shown that increased exposure to a particular structure, such as object relative clauses, results in less difficulty (MacDonald & Christiansen, 2002). This extends to human comprehenders as well. People who read more sentences with relative clauses experienced less

difficulty with those structures (Wells et al., 2009). Critically, these findings suggest that language experience drives individual variation in processing; the amount of experience has an effect on comprehension.

In addition, previous work has investigated whether syntactic priming could rapidly affect syntactic expectations, e.g. after exposure to only one instance of a syntactic structure. Comprehenders primed with a specific structure, such as a double-object dative (*show the horse the book*), showed greater preference for the primed structure relative to alternative structures (e.g. *show the horn to the dog*), regardless of whether there was a lexical overlap for either the critical verb or noun (Thothathiri & Snedeker, 2008; see also Kim, Carbary, & Tanenhaus, 2014). Some argue that the persistence of syntactic priming across multiple sentences stems from implicit learning (Bock & Griffin, 2000; Chang et al., 2000). On this view, syntax is acquired implicitly through prediction error: the difference between what is observed and what is expected prior to the observation (i.e. error-based learning; Chang, Dell, & Bock, 2006).

In contrast, others attribute syntactic priming to a residual activation account (e.g., Pickering and Branigan, 1998; Branigan, Pickering, & Cleland, 1999). This approach argues that priming increases activation of the connections between lexical units and syntactic structures in memory. Due to the recent exposure of the syntactic structure, this leads to a higher level of residual activation. The parser then selects the structure that is more active in memory at that time, resulting in a short-term priming effect. Support for a residual activation account comes from an increase in the magnitude of the priming effect when there is a lexical overlap in the prime and target sentence ("lexical boost", Cleland & Pickering, 2003; Pickering & Branigan, 1998). Similar to implicit learning accounts, this account predicts an effect of recent experience. The difference is that the effect of experience is short-lived and does not lead to long-term

learning. The current study does not directly test between a residual activation account and an implicit learning account, despite differences between accounts.

The argument for implicit learning is the basis for recent work on syntactic adaptation; comprehenders exposed to unexpected structures update their expectations for upcoming structures in order to reduce surprisal, thereby allowing for efficient language processing. For example, comprehenders can adjust their syntactic expectations after exposure to sentences that violate specific verb biases, such as whether a verb is more likely to occur as a main verb (*The soldiers warned the people*) or as an embedded verb in a relative clause (*The soldiers warned about the dangers conducted...*). Initially, comprehenders experience more difficulty with sentences where the verb is embedded within the relative clause. After repeated exposure, difficulty decreases for the less preferred relative clause interpretation, which implies that comprehenders have come to expect the relative clause interpretation over time (Farmer, Fine, & Jaeger, 2011; Fine & Jaeger, 2016). This effect has been replicated, but the effect was small and required many participants to detect (Prasad & Linzen, 2020).

By that same logic, repeated exposure to the relative clause interpretation should change expectations for the preferred main verb interpretation as well. Fine et al. (2013) found that comprehenders exposed to unambiguous reduced relative clauses at the beginning of their experiment experienced more difficulty with the main verb disambiguation. They argued that this difficulty stemmed from an increase in surprisal; comprehenders rapidly shift their expectations in order to align with the speaker's preferences. However, Harrington Stack, James, & Watson (2018) failed to replicate their findings, despite a larger sample size.

In sum, while this line of studies provides causal support, there are two problems: 1) these studies (e.g. Fine et al., 2013) do not separate out the effects of distribution and exposure,

and 2) the syntactic adaptation effect is not always replicable, such as in the case where the preferred alternative is made infrequent. This raises questions about the role of relative frequency, as it is not clear how it affects syntactic processing.

Why the role of distribution needs tested

The lack of replicability raises concerns about the syntactic adaptation effect, and possibly the theories behind it. Researchers have argued that exposure to low-probability structures violates expectations, which in turn leads to rapid adaptation (Farmer et al., 2011; Fine et al., 2013). This argument depends on the assumption that comprehenders have a mental representation of the probabilities associated with each structure. Therefore, if comprehenders form expectations about upcoming syntactic structures using prediction error, then these adjustments can only occur if 1) comprehenders have knowledge of the frequency statistics of different structures, and 2) can extract probability estimates from those statistics. Critically, neither of these assumptions has been directly tested, which may serve as one explanation for why the syntactic adaptation effect is hard to detect. Rather than assuming that comprehenders have implicit knowledge of a probability distribution computed across syntactic structures, the current study aims to investigate whether comprehenders are sensitive to syntactic distributions in the first place.

The motivation for the current study comes from experience-based models of syntactic processing. Distribution plays an important role in these models. Both constraint-based approaches and probabilistic models claim that comprehenders have access to the co-occurrence frequency between a word and a particular structure, as acquired through experience. In turn, comprehenders use these frequency statistics to compute the probabilities of alternative interpretations, which affect processing. These theories have been supported by correlations

between corpora and experimental data; infrequent structures as determined by corpora tend to be processed with more difficulty. However, correlation does not imply causation. In order to directly test whether comprehenders develop such implicit knowledge, the linguistic environment needs to be manipulated.

Studies investigating syntactic adaptation have directly changed the linguistic environment, however, they fail to separate the effects of exposure from distribution. Fine et al. (2013) exposed their participants to 50% reduced relative clauses and 50% main verb structures. This increased the relative percentage of relative clauses from around 1%, across all verb types (an estimate from corpora; Roland et al., 2007), to 50%. Ultimately, this increase changes both the relative frequency and the raw frequency to this specific structure. Therefore, it is unclear what effect the change in distribution has on comprehension, as it cannot be separated out from overall exposure.

Another problem is that the syntactic adaptation effect is hard to detect, even with enough statistical power. One possibility for these mixed findings is that recent exposure cannot overcome someone's lifetime experience with a specific syntactic structure, at least within one experimental session. Experience-based models are heavily based on connectionist approaches (Bates & MacWhinney, 1987; Elman, 1990), in which network weights are adjusted based on the connections between co-occurrences (MacDonald & Christiansen, 2002). Exposure to infrequent relative clauses may change the weight of which interpretation is preferred, leading to lower expectations for the originally preferred structure. Since the preference for the relative clause is higher, this competes with the main verb interpretation. However, Harrington Stack et al. (2018) found that exposure to the reduced relative clauses has no effect on sentences with a main verb

interpretation. This suggests that brief exposure was enough to change the weights for the infrequent relative clause structure, but not enough to affect the frequent main verb structure.

The current study aims to solve both of these issues. Within each experiment, the raw frequency of the target structure is kept constant, while only relative frequency is manipulated. Second, baseline experience is controlled since the manipulated structure is unfamiliar to most people. This minimizes any noise that could have occurred from lifetime experience.

In conclusion, theoretical models claim that comprehenders acquire implicit knowledge of distributional information of syntactic structures. Recent work in syntactic adaptation uses those models, in addition to implicit learning, as a basis for how comprehenders can rapidly adapt to novel linguistic environments. However, there have been mixed results in the syntactic adaptation literature, even with enough statistical power to detect an effect (Harrington Stack et al., 2018; Prasad & Linzen, 2020). This raises questions about the core underlying assumptions shared across experience-based models: 1) Do comprehenders have implicit knowledge of the distribution of specific syntactic structures? and 2) Do they calculate specific probabilities based on the distribution?

Potential theoretical frameworks

Previous work has not directly tested relative frequency independent of raw frequency, therefore it is not clear what kind of effect it will have on comprehension. There are three possible theoretical frameworks that could account for the role of distributional information on syntactic processing. The first is an approach where relative frequency plays no role, and an increase in raw frequency leads to ease of processing. The second possibility is that distribution does affect processing, but comprehenders can only acquire rough estimates of the relative frequencies for the target structure and its competing alternatives. Lastly, the third possibility is a

theoretical approach where distributional information matters, and comprehenders are sensitive to the fine-grained probabilities associated with each syntactic structure.

No role of relative frequency

It is possible that only raw frequency has an effect on syntactic processing, rather than relative frequency. Infrequent structures such as reduced relative clauses may be processed with more difficulty because comprehenders do not have enough overall experience that particular syntactic structure, and increasing the raw frequency of reduced relative clauses would lead to less difficulty. This is consistent with studies showing syntactic priming, where one instance of a given structure leads to production of that same structure (Bock, 1986), or facilitation during comprehension (Thothathiri & Snedeker, 2008). This framework would also be consistent with studies on syntactic adaptation, which shows facilitation over time after brief exposure (Fine et al., 2013; Fine & Jaeger, 2016).

Currently, constraint-based models propose that information on the co-occurrence frequency between a word and a particular structure is stored in the word's lexical entry (MacDonald et al., 1994; Seidenberg & MacDonald, 1999). When a word is read, multiple alternative structures are activated in parallel and available to the comprehender, and the structure with the most activation is selected while competing structures lose out on selection. If relative frequency plays no role, then this suggests a model where alternative structures are not considered as competition, and only the target structure is activated. This would suggest that only information on the verb and the co-occurring target structure is stored in memory, with no other information on competing structures. If this is the case, then there should be no difference between a distribution with a high proportion of the target structure and a distribution with a low proportion of the target structure.

Rough estimates of relative frequency stored

Another possibility is that relative frequency does matter, and it has an effect on syntactic processing over and above raw frequency. This framework proposes that comprehenders learn the distributional properties of language, but are only sensitive to *rough estimates* of co-occurrence frequencies between a word and its possible syntactic structures. In this case, comprehenders are only sensitive to which syntactic structures are frequent and which ones are infrequent given the lexical item, but do not have implicit knowledge of the fine-grained probabilities associated with each syntactic structure. Therefore, infrequent verb-structure co-occurrences are processed with more difficulty due to competition from more frequent alternatives. If there are multiple frequent alternatives, then contextual constraints interact with frequency to select the best interpretation.

This proposed framework is consistent with constraint-based models, where the mechanisms underlying processing involve selection of the most activated interpretation based on contextual and frequency information (MacDonald et al., 1994; Tanenhaus et al., 1995). However, it takes it one step further by specifying the level of granularity at which frequency information is stored. Consistent with constraint-based models, information on the relative frequency between a word and each of its possible syntactic structures is stored in memory. When that word is activated, the syntactic structure with the most activation relative to the alternative structures is selected. This activation is based on contextual constraints and frequency constraints. If comprehenders are sensitive to rough estimates of distributional information, then there should be a difference in syntactic processing between a distribution with a high proportion of the target structure vs. a distribution with a low proportion of the target structure.

Fine-grained estimates of relative frequency

Similar to the previous account, the final possibility is that comprehenders are sensitive to relative frequency, but at a fine-grained level. In this framework, probabilities of each syntactic structure are stored alongside the lexical entry. During processing, probabilities for each possible structure are computed based on the linguistic input, and then are ranked in order of highly probable to improbable. This takes the previous account one step further by assuming that comprehenders have fine-grained probabilistic knowledge of each verb-argument co-occurrence.

This framework is consistent with probabilistic models of syntactic processing (Hale, 2001; Jurafsky, 1996). It would also be consistent with implicit learning accounts, and by extension syntactic adaptation, which claim that comprehenders update their expectations through prediction error (Chang et al. 2006; Fine et al., 2013). Therefore, in order to update their expectations, comprehenders must have prior beliefs in order to calculate prediction error. For example, given the input *The soldiers warned…,* comprehenders may expect that *warned* will occur as the main verb with 90% probability, based on prior beliefs. If instead the verb is embedded in a relative clause, then the difference between what was observed and what was expected (i.e. prediction error) is calculated in order to update the probability of the main verb interpretation. This is also consistent with constraint-based models, but only because those models do not specify whether comprehenders have fine-grained or rough estimates of frequency statistics. If comprehenders have fine-grained probabilistic knowledge, then they should be sensitive to small differences in the relative frequency of two syntactic structures.

Generalization of verb-specific distributions

If comprehenders are sensitive to the relative frequency of syntactic structures, it raises further questions about how these syntactic structures are represented. Do comprehenders keep

track of distributional information on an abstract level? Or are representations tied to a specific lexical entry, and not generalized across words?

Experience-based models of syntactic processing imply that comprehenders are sensitive to the statistical regularities of different syntactic structures. However, there is debate over the level of detail comprehenders can track statistically. For example, if comprehenders keep detailed statistics based on context and lexical effects alone, this would suggest storage of fine-grained records on verb-argument structures based on specific context and specific lexical items (Spivey-Knowlton & Sedivy, 1995). This represents a purely fine-grained approach, in that comprehenders do not consider statistics pooled across lexical items during comprehension. This requires comprehenders to make use of fine-grained statistics, which though computationally expensive, allows for more precision. In addition, it entails that the comprehender must have encountered that specific verb-argument co-occurrence in the past, meaning no generalization can occur based on exposure to a similar structure.

Constraint-based lexicalist theories also make a similar claim: comprehenders are sensitive to the frequency of co-occurrence between a verb and its preferred syntactic structure. In contrast to the purely fine-grained account, constraint-based accounts stem from a connectionist approach; exposure to a similar structure as one previously encountered will not result in large weight changes in the network (MacDonald et al., 1994; MacDonald & Christiansen, 2002). Due to the nature of this approach, constraint-based accounts predict that generalization will occur across similar verbs for the same structure. Therefore, those accounts could be defined as a mixed-grain approach with an emphasis on lexical information. This contrasts with course-grain accounts that claim that structural information have a large influence on processing, while finer details like lexical information are not considered until afterwards

(Cuetos, Mitchell, & Corley, 1996; Mitchell et al., 1995). This idea of lexical information not playing a role until later is related to accounts that propose modular, two-stage mechanisms, where only one interpretation is considered at a time and lexical information is not integrated with the initial parse of a sentence (e.g. "Garden-path model": Frazier, 1987).

Support for generalizing verb-specific distributions to other verbs can be found in the field of language acquisition. Learning about verbs and the syntactic structures they are constrained to (i.e. subcategorization) poses a problem to language learners because some verbs extend to new structures (e.g. *she walked, she walked her dog*), while others do not (e.g. **she brought*). One theory is that learners track frequencies of different verb-structure combinations in order to make inferences about verb-structure pairs that have never been encountered. This approach is similar to experience-based models of processing with an emphasis on lexically-based, verb-specific statistics (MacDonald et al., 1994; Tanenhaus & Trueswell, 1995). This is not surprising as the basis of experience-based models of syntactic comprehension stems from connectionist models in language acquisition (Bates & McWhinney, 1987; Elman, 1990), in which statistics play a role in learning different aspects of language such as speech sounds (Saffran, Newport, & Aslin, 1996), word learning (Graf Estes et al., 2007; Mirman et al., 2008), phonotactic regularities (Chambers, Onishi, & Fisher, 2003), and grammar (Gómez & Gerken, 2000). Therefore, evidence that statistical patterns influence acquisition can point to expected statistical patterns in comprehension.

Work from Wonnacott et al. (2008) provides evidence of learners acquiring distributional properties of both verb-specific and verb-general argument structures. A set of artificial languages was created to include three verb classes and two argument structures; two classes that were constrained within one out of the two structures, while another set of verbs alternated

between both structures. The two argument structures occurred at varying frequencies and differed in word order, which created a temporary ambiguity at the verb that could only be resolved at the end of the sentence. In order to successfully learn the new language, only the constraints between the verb and its co-occurring structure could be used to disambiguate between the two structures. Wonnacott et al. (2008) showed that participants correctly produced and identified the correct structure for each verb in the one-structure verb class, suggesting that they clearly learned the subcategorization restrictions for verbs constrained to one structure. For the alternating verb class, generalization depended on the frequency of each individual verb and the number of verbs in the class. When the alternating verbs class contained more verbs and varied in frequency, participants were more likely to generalize and less likely to pay attention to verb-specific restrictions. When there was a small class of alternating verbs, learners acquired both verb-specific constraints and verb-general constraints. These results suggest that learners can use distributional information to infer when generalization is appropriate.

Frameworks accounting for generalization

Theoretical models of processing make different predictions about whether syntactic information can generalize across lexical items. One possibility is that generalization may not occur if comprehenders only keep track of verb-specific statistics. On the other hand, the other possibility is that generalization does occur on an abstract level, but generalization may only be limited to the underlying syntactic representation. Lastly, another possibility is that comprehenders are sensitive to distributional information on a verb-general level. In other words, information on relative frequency can be generalized over a subset of lexical items.

No generalization

The first possibility is that generalization in syntactic processing does not occur. This

would fit an account where syntactic representations are tied to specific lexical items. Therefore, when comprehenders encounter a verb embedded within a specific syntactic structure, it only strengthens the combination of the lexical item and the syntactic structure. In order to learn about other verbs taking those same arguments, comprehenders must encounter those sentences separately. For example, comprehenders could learn that the verb *needs* can be used in *The dog needs washed.* However, they would not be able to generalize *wants* to the same structure, as in *The dog wants washed,* because they have never encountered that verb-structure pair, despite already being exposed to the underlying syntactic structure. They would have to encounter *The dog wants washed* in order to form a new link between the syntactic structure and the verb *wants*. This would be consistent with a fine-grained lexicalist approach (e.g. Spivey-Knowlton & Sedivy, 1995), where syntactic representations are specifically tied to one verb. This account is also consistent with studies that find a lexical boost in syntactic priming (e.g. Pickering & Branigan, 1998), where the magnitude of the priming effect is increased when there is lexical overlap in the prime and target sentence.

Generalization of underlying structure

The second possibility is that generalization occurs on an abstract level. Exposure to a structure strengthens its underlying syntactic representation for all lexical items, rather than only one. This is supported by studies showing a syntactic priming effect in the absence of any lexical or contextual overlap (Kim et al., 2014; Thothathiri & Snedeker, 2008). It is also consistent with constraint-based accounts, which predict that exposure to similar structures will not result in large weight changes in the network (MacDonald et al., 1994; MacDonald & Christiansen, 2002). Furthermore, studies show adaptation to a particular syntactic structure, such as reduced relative clauses, across a subset of verbs (Fine et al., 2013; Harrington Stack et al., 2018).

Therefore, it is possible that any verb-structure co-occurrence strengthens the underlying syntactic representation, which theoretically could lead to generalization. For example, comprehenders could learn the underlying structure *The dog needs washed,* and would be able to generalize the structure to the verb *wants* without any difficulty. However, it is possible that there may be lexical and contextual constraints. For example, some verbs may not take certain arguments (e.g. **she brought*), or may not be plausible given the context (e.g. #*The meal wants cooked*).

Generalization of distributional information

The third possibility is that both the underlying structure and its information on relative frequency is represented on a verb-general level. In other words, comprehenders could learn the frequency of a verb-structure co-occurrence such as *The dog needs washed* relative to a competing structure *The dog needs washed toys,* and this apply it to the same structure, but to a different verb, as in *The dog wants washed* and *The dog wants washed toys.* This account implies that comprehenders do not store distributional information separately for each lexical item, but rather that information can be generalized over a subset of items. This logic is used in syntactic adaptation studies, in which syntactic expectations are calculated and adjusted over a subset of verbs (Fine et al., 2013). Critically, conclusions from syntactic adaptation studies suggest that comprehenders shift their expectations to match the relative frequencies of each syntactic structure in the linguistic environment, across a subset of verbs. This suggests that distributional changes affect the syntactic expectations across lexical items, although as with the previous account, contextual and lexical constraints most likely interact with frequency information.

In addition, artificial language learning studies (e.g. Wonnacott et al., 2008) show that frequency information affects when generalization does or does not occur. This implies an

account where information on relative frequency is accessible on a verb-general level, it is used to make inferences about when to generalize. For example, if a comprehender learns that a large number of verbs can be used in a syntactic structure, they may be more willing to generalize that structure to new verbs. On the other hand, if only one verb is used within the syntactic structure, then generalization may only be limited to one or two new verbs. This is also likely to be affected by the semantic similarity between verbs, such as *wants* and *needs.*

Summary and project goals

The current study aims to test whether comprehenders are sensitive to syntactic distributional information by manipulating the relative proportions of two syntactic structures. There are two aims to the study. Aim 1 is to investigate whether changes to the relative frequencies of syntactic structures affect on-line sentence parsing, as measured by reading time. For Experiment 1, the primary question is whether comprehenders can acquire an implicit knowledge of syntactic distribution. This is tested by creating two distributions, one with a high relative frequency of the dialectal syntactic structure, and one with a low relative frequency. Critically, I expect that distribution will play a role as suggested by experience-based models, independent of overall exposure to the structure. I hypothesize that a distribution with a higher relative frequency of the unfamiliar dialectal structure will result in faster adaptation compared to a lower relative frequency.

Experiment 2 directly follows up Experiment 1, but investigates whether comprehenders are sensitive to distributional differences even when the same structure is in the majority for both distributions. Probabilistic models of syntactic comprehension predict that the probabilities of different syntactic structures are ranked in order to select the best possible parse (e.g. Jurafsky, 1996). If syntactic expectations are based on the probability of each structure, comprehenders

need to know specific probabilities in order to rank them. Similarly, research on syntactic adaptation relies on comprehenders learning from prediction error, which also implies probabilistic knowledge (e.g. Fine et al., 2013). On the other hand, comprehenders may only pay attention to the frequent alternative, which would suggest an account where only rough estimates of relative frequency are acquired. Experiment 2 tests this by asking whether comprehenders categorize syntactic structures into majority vs. minority, or if they have fine-grained knowledge of specific probabilities. If the latter is the case, then differences in processing difficulty are expected between distributions where the relative frequency of the syntactic structure is higher than its competitor.

Aim 2 is to investigate whether comprehenders can generalize a distribution to another verb. Experiment 3 tests whether the verb-specific distribution of the dialectal *needs* structure can be generalized to the same structure but with the verb *wants*. The verbs *needs* and *wants* share similar syntactic properties. For example, both *needs* and *wants* can take a subject as an argument, whether it is an expletive subject (*It needs/wants to rain*) or not (*The child needs/wants food*; Becker, 2005). The ability to switch between these two constructions makes *wants* a good candidate for investigating generalization of the dialectal structure, as it behaves similarly to *needs*.

In regards to generalization, Wonnacott et al. (2008) found that people could use verb-general distributional information when learning subcategorization constraints in an artificial language. In addition, Kaschak & Glenberg (2004) showed that exposure to the dialectal *needs* structures facilitates processing to the same structure but with the verb *wants*. However, these studies failed to separate effects of relative frequency and raw frequency. Therefore, if comprehenders only keep track of verb-specific statistics, then no generalization should occur. In

contrast, if comprehenders do generalize, then the distribution of the dialectal *needs* structure should transfer to a similar verb used in the same construction.

The use of the dialectal structure *The meal needs cooked* in the current study serves as a test case to study the role of relative frequency on processing. Because of its unfamiliarity, most people may think the sentence is ungrammatical. Since most work in syntactic adaptation and syntactic priming focus on grammatical structures, the role of ungrammaticality is still somewhat unclear. For example, Sprouse (2007) found that for island violations (e.g. *Who do you wonder whether Susan met?*), there was no improvement in acceptability judgement tasks after exposure to these ungrammatical structures. On the other hand, Ivanova et al. (2012) found that sentences primed by ungrammatical sentences using incorrect or novel verbs still led to a priming effect. They argue that in contrast to Sprouse (2007), syntactic representations formed from ungrammatical structures are similar to those for grammatical sentences. Other work has also shown priming of ungrammatical structures, including priming of island violations (Do & Kaiser, 2017; Luka & Barsalou, 2005; Snyder, 2000). Relevant to the current study, Kaschak & Glenberg (2004) show that reading times for the dialectal *needs* sentences are the same as the standard *needs to be* sentences by the end of the experiment (see also, Fraundorf & Jaeger, 2016). This suggests that at some level, the syntactic representations of ungrammatical sentences are similar to well-formed sentences. However, it may be the case that the priming effect may vary depending on *how* ungrammatical a sentence is. For example, people may find an island violation (e.g. *Who did you leave the party because Mary kissed?*) more ungrammatical than the dialectal *needs* structure. This may in turn lead to a smaller or no priming effect.

Overall, the current study is made up of three experiments. In Experiment 1, a self-paced reading task is used to test differences between two distributions; a distribution with 80%

dialectal *needs* sentences and 20% modifier sentences, and a distribution with 40% dialectal *needs* sentences and 60% modifier sentences. Then, in Experiment 2, changes are made so that both distributions have a high proportion of dialectal sentences. Lastly, Experiment 3 uses the same relative frequencies as Experiment 1, but tests whether the distribution of the dialectal *needs* structure transfers over to a similar verb that uses the same dialectal structure.

Experimental approach

The stimuli and design for this study were similar across all experiments. The relative frequency of the dialectal structure (*The meal needs cooked before…*) was manipulated while controlling for overall exposure. The modifier structure (*The meal needs cooked vegetables*) acted as a competitor to the dialectal *needs* structure. This allowed for both structures to be syntactically ambiguous until two words after *needs*. The relative frequency of the dialectal structure and the modifier structures was manipulated to test whether participants were sensitive to distributional information. All experiments were a 2 by 2 between-subjects design. Participants were assigned to one of two distributions: either an 80-20 condition or a 40-60 condition (Experiments 1 & 3), or either a 90-10 condition or 66-33 condition (Experiment 2). These numbers represent the relative percentages of the two competing syntactic structures (dialectal *needs* and modifier structure respectively). The location of modifier structures in the experiment was controlled so that at any given dialectal structure, the distribution of dialectal to modifier sentences would be as close to the target distribution as possible. The number of unrelated fillers varied based on condition, and differed in both structure and verb.

A self-paced reading task was used for all experiments, where participants read sentences in a moving window display at their own pace. Participants read a specific number of dialectal *needs* sentences e.g. *The fire needs stoked to keep it from burning out* and a specific number of

the competing modifier structure e.g. *The meal needs cooked vegetables.* The proportions of these two structures was dependent on condition, where the relative proportion of the needs structure compared to the modifier structure is manipulated between participants. To control for overall adaptation to the self-paced reading task, the number of sentences participants read were the same across condition. After reaching the end of the sentence, participants answered one comprehension question to ensure they read the sentence.

General analytic approach

Across all experiments, reading time was analyzed at disambiguation (two words after *needs*) in R (version 4.0.2; R Core Team, 2016), using a linear mixed-effects modeling framework from the lme4 package (Bates et al., 2015). The disambiguating word was analyzed for the primary question, which was a function word. Though the disambiguating word was a function word, this is the region where the slowdown occurred both in Kaschak & Glenberg (2004) and a previous pilot study. Since the self-paced reading literature suggests that effects may spill over, secondary analyses were included to investigate whether any effects extended to three words after disambiguation, with each word in a separate analysis. In addition, another secondary analysis with participant age was also included to test learning effects across age at the critical word. All mixed effects models employed a maximal random effects structure, incorporating random intercepts for both items and participants, as well as random slopes for each predictor (Baayen, et al., 2008; Barr et al., 2013; Raudenbush & Bryk, 2002). Responses from the self-paced reading task were corrected for both word length and log item order. The *p*-values for all pairwise comparisons were adjusted using Tukey's method.

CHAPTER 2: TEST OF DISTRIBUTIONAL KNOWLEDGE

Experiment 1

Motivation

The objective of Experiment 1 was to determine whether participants read the dialectal *needs* sentences faster over time in the 80-20 distribution compared to the 40-60 distribution. The second aim was to replicate Kaschak & Glenberg (2004), and see whether participants could adapt to a novel syntactic structure. In the primary task, participants read 80 sentences in total. Out of these sentences, 20 of them were dialectal sentences (e.g. *The meal needs cooked before the guests arrive*). To get a measure of processing, reading times were obtained for the dialectal sentences during disambiguation, which occurred two words after *needs.* The key question was whether syntactic processing would be affected by the frequency of the dialectal structure relative to its competing structure. To test this, the frequency of the competing, modifier sentences was manipulated to create two different distributions: one where there more modifier sentences compared to the dialectal sentences, and another where there were less.

Power analysis

The number of participants for Experiment 1 was determined via a power analysis based on previous data from a pilot study. The pilot study had 39 participants and was a between-subjects design; participants were assigned to either the 80-20 or 40-60 distribution with only the dialectal sentences. Participants in the condition with the higher proportion of dialectal *needs* structures had a faster rate of adaptation (Langlois, AMLaP 2020). Recent studies have found that self-paced reading tasks investigating syntactic adaptation are frequently under-powered

(Harrington Stack et al., 2018; Prasad & Linzen, 2020). In order to calculate power, data from this pilot study were used to conduct power simulations using the 0-1 method (Muthén & Muthén, 2002). Responses for each simulated dataset were generated using the fixed effect estimates, participant and item random intercept estimates, and the error estimate from the pilot data. Each dataset was fit to a linear mixed effects model. If the interaction term was significant at a *p*-level of .05, it was coded as 1, otherwise 0. Using 1000 simulated datasets, 99.5% power for the interaction between item order and condition could be achieved with 120 participants. The target number of participants was then doubled to account for the change in design for Experiment 1, resulting in a target number of 240 participants. For Experiments 2 & 3, this target number was increased to 320 participants to account for changes in experimental design.

Methods

Participants

275 participants were recruited from Amazon Mechanical Turk, and received $2.00 in exchange for completing the study. To be included in analysis, participants had to indicate that they were a native English speaker. 14 participants were excluded for not meeting this criterion. In addition, in order to minimize baseline experience to the dialectal sentences, participants who were very familiar with the dialectal sentence prior to the experiment were excluded from final analysis. Participants were asked whether they had any experience with sentences like *the car needs washed* prior to the experiment. 28 participants indicated that they often heard these types of sentences in their daily life. This left a total of 233 participants.

Materials and design

Experiment 1 was a 2 by 2 between-subjects design with two distributions and an ambiguous and unambiguous condition. In the ambiguous condition, participants read dialectal

needs sentences such as *The meal needs cooked before the guests arrive.* In the unambiguous condition, these sentences were replaced with the English standard version, *The meal needs to be cooked before the guests arrive.* In addition to these target sentences, participants also read modifier sentences such as *The meal needs cooked vegetables.* The number of modifier sentences varied depending on which distribution the participant was assigned to: the 80-20 distribution or the 40-60 distribution. The numbers in each distribution represent the relative percentages of the two syntactic structures, the dialectal or standard *needs* and modifier structure respectively (Table 1). In the 80-20 distribution, participants read 20 target *needs* structures (80%), 5 modifier structures (20%), and 55 unrelated filler sentences. Likewise, in the 40-60 distribution, participants read 20 target *needs* structures (40%), 30 modifier structures (60%), and 30 unrelated filler sentences. Modifier structures were presented at specific timepoints in the experiment, so that at any given target structure, the distribution of target to modifier sentences would be as close to the distribution as possible (Figure 1). Following the verb *needs*, modifier structures never shared the same past participle or sentence with the dialectal or standard sentences. This 2 by 2 design resulted in four lists: an 80-20 distribution with dialectal sentences, a 40-60 distribution with dialectal sentences, an 80-20 distribution with standard sentences, or a 40-60 distribution with standard sentences. The stimuli for Experiment 1 are in Appendix A.

Table 1. Number of each sentence type in each list for Experiment 1.

	80-20	**40-60**
Ambiguous	20 dialectal *needs* 5 modifiers 55 fillers	20 dialectal *needs* 30 modifiers 30 fillers
Unambiguous	20 standard *needs* 5 modifiers 55 fillers	20 standard *needs* 30 modifiers 30 fillers

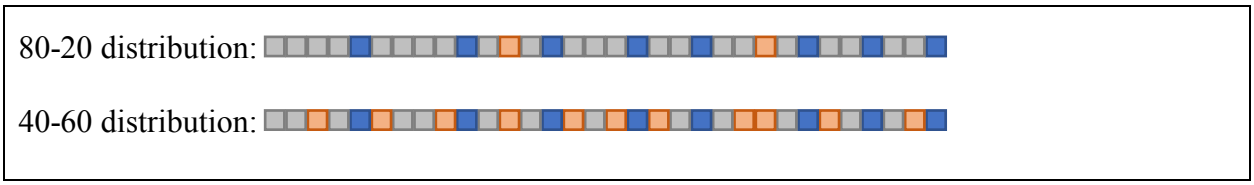

Figure 1. A representation of the order that sentences are presented in for each distribution, for the first half of Experiment 1. Blue squares represent the dialectal/standard sentences, orange squares represent modifier sentences, and gray squares represent unrelated filler sentences.

Procedure

The experiment was administered using PennController for IBEX (PCIbex; Zehr & Schwarz, 2018). Prior to beginning the task, participants completed a background questionnaire that consisted of questions such as English competency, other languages, age, and education. After completing the background questionnaire, participants were told that the task involved reading sentences on the screen one word at a time, and then answering a comprehension question about the contents of the sentence. After the initial instructions, participants read three sentences and answered three questions in this manner in order to get used to the task. After completing the practice trials, participants moved forward to the experimental task.

Participants read sentences in a moving window display one word at a time at the participant's own pace. Upcoming words were represented by blank lines, and participants pressed the spacebar to advance to the next word. After reaching the end of the sentence, participants answered one comprehension question to ensure they read the sentence. The question occurred on a separate page from the sentence, and was accompanied with two answer choices. Answer choices were counter-balanced so that the correct answer was the top answer 50% of the time. If participants answered the question incorrectly, they were given feedback along with a 5 second delay before the next trial instead of 700ms.

After completing the experiment, participants were asked about their experience with the experiment and with sentences like *The car needs washed.* In the first part of this post-questionnaire, participants were asked if they noticed anything odd about the sentences that they read. If yes, they were then asked to describe an example of what they found odd about the sentences. In the second part, participants were told that some people say *The car needs washed*, instead of *The car needs <u>to be</u> washed*. They were asked whether they had heard people use these sentences outside of experiment (Yes/No). Then, they were asked about their familiarity with these sentences (Prior to this experiment, how often did you hear sentences like *The car needs washed*?), with the answer choices being "Never", "Rarely", "Sometimes", and "Often". Lastly, participants were asked to report whether they had ever lived in Pennsylvania or Colorado in two separate questions. They were also asked to choose the best option that described their living situation in either state (e.g. "Grew up there but no longer live there"). See Appendix D for the post-questionnaire. The same post-questionnaire was given to every participant regardless of the condition they were in.

Analytic approach

Reading times were analyzed at disambiguation (two words after *needs*) in a linear mixed-effects modeling framework. The disambiguating word in Experiment 1 was always one of the following function words: *before*, *to*, *so*, *since*, or *for*. The primary predictors in the model were distribution (80-20 vs. 40-60), ambiguity condition (standard vs. dialectal *needs*), and item order. Distribution was contrast-coded, with the 80-20 distribution as +.5 and the 40-60 distribution as -.5. The ambiguous condition was coded as +.5 while the unambiguous condition was coded as -.5. Item order was log-transformed and grand-mean centered. The final model included all two-way interactions between the primary predictors, and the three-way interaction

between distribution, ambiguity, and item order. Planned comparisons with corrected *p*-values were used to probe any significant interactions. Models included random intercepts for both item and participant. Random slopes were not included because they either caused the model to not converge or were estimated to be zero.

Data Processing and exclusions

Raw reading times that were very short (< 100ms) or were longer than two times the standard deviation above the mean were excluded from analysis. This affected 2.16% of the data. In addition, trials where the comprehension question was answered incorrectly were also excluded, which affected 3.39% of the data.

Following the self-paced reading literature, reading times were corrected for word length and baseline reading speed (Ferreira & Clifton, 1986). A linear mixed effects regression was performed on the reading times for the unrelated filler items rather than all items. Predictors in this regression included word length and a random intercept on the participant level to account for baseline reading speed. For most participants, this was their first time encountering the dialectal structure. Therefore, reading times for these sentences would not accurately reflect baseline reading speed. In addition, item order (log-transformed) for the filler items were also included in the regression. Reading times over the course of the experiment tend to decrease due to participants adapting to the task. This task adaptation is separate from adapting to the syntactic structure. Regressing out item order allows for separation of syntactic adaption from task adaptation. Any changes in the reading time of the critical items is then due to syntactic adaptation, and not to the nature of the task.

The reading time regression model was then used to predict reading times for the disambiguating word in the dialectal/standard sentences (e.g. *before*). The reading times used in

this model was not log-transformed, as transforming the data did not lead to any significant improvements in model diagnostics.[1] Residual reading times for the disambiguating word were obtained by subtracting the predicted reading times from the observed reading times. These residual reading times were then analyzed in the final model, and are a measure of reading time that accounts for task adaptation, word length, and participant reading speed. This procedure was extended to the unambiguous condition despite the use of the standard structure to keep things consistent.

The use of this two-step regression procedure, in which residuals from a previous regression are used as a dependent measure in a subsequent regression, has recently become controversial in psycholinguistics. Residuals are often used to control for unwanted effects in multivariable datasets, specifically in the fields of ecology and finance. Freckleton (2002) and Chen, Hribar, & Melessa (2018) show that the bias in coefficient estimates and standard errors increase as a function of the correlations between predictors. Instead, they conclude that the simplest solution is to use a single multivariate regression model to control for confounding predictors.

There are two reasons why the two-step regression procedure is justified in the current study. The first is that none of the variables are correlated with each other across the two regression models. Though item order is included in both models, in the reading time model, only the item order for the filler items are included. This variable is different from the item order of the target sentences. The lack of collinearity across these predictors leads to less of a bias in parameter estimates and standard error. In contrast, other adaptation studies include order for all the items in both regression models (Fine et al. 2013). This may pose more of a problem because

[1] Models diagnostics include checking for multicollinearity, non-normality, and homoscedasticity.

the same data is being regressed twice, and in this case the variable is perfectly correlated with itself.

Second, task adaptation has to be controlled for in order to better understand the effect of syntactic adaptation over and above task adaptation. However, the item order variable in a single multivariate regression cannot distinguish between these two types of adaptation. Prasad & Linzen (2020) used a single model regression with log reading times as the dependent variable and two predictors for item order: stimulus number and critical item number. The stimulus number represents the total number of sentences a participant has seen so far, while critical item number represents the number of critical sentences seen. This allowed for separation, as stimulus number represents overall task adaptation while critical item number represented syntactic adaptation to only the critical sentences. However, including both of these variables introduces multicollinearity into the model, as these two variables are highly correlated with each other. This leads to unreliable coefficient estimates and more uncertainty in parameter estimates.

In sum, though there are problems with both of these methods, using the two-step regression procedure is slightly better than using a single regression model given the reasons stated above. It also allows for better visualization of the effect of syntactic adaptation happening over the course of the experiment. In addition, previous studies use residual reading time as their dependent measure, which allows for comparison across studies. With that said, using a single regression that regresses raw reading time on all the predictors led to similar results.

Results

Primary analysis

To test whether there was a difference in reading time between the 80-20 distribution and the 40-60 distribution, the target *needs* structures were analyzed at the disambiguating word (e.g.

before). In the unambiguous condition, the same word was analyzed as in the dialectal sentences despite the lack of ambiguity. On average, participants were faster at reading the critical word in the standard sentences relative to the dialectal sentences (Figure 2). This emerged as a main effect of ambiguity in the model; there was a significant effect of ambiguity condition on residual reading times ($\beta = 31.08$, SE = 5.23, $t = 5.95$, $p < .001$). There was no main effect of distribution, indicating no difference in reading time between the two distributions. In addition, there was a main effect of log item order ($\beta = -17.11$, SE = 5.55, $t = -3.09$, $p < .01$), indicating that there was syntactic adaptation regardless of condition over and above task adaptation. There was also a significant two-way interaction between log item order and ambiguity ($\beta = -10.74$, SE = 4.91, $t = -2.19$, $p = .029$); participants adapted at a faster rate to the target sentences in the ambiguous condition than the unambiguous condition.

The primary question of Experiment 1 was whether participants are sensitive to changes in relative frequency independent of total exposure. Over the course of the experiment, participants in the ambiguous condition read the critical word faster in the 80-20 distribution relative to the 40-60 distribution (Figure 3). This pattern emerged as a significant three-way interaction between distribution, ambiguity, and log item order ($\beta = -22.24$, SE = 9.83, $t = -2.26$, $p = .024$). Residual reading times for the critical word decreased faster for the ambiguous 80-20 condition than the 40-60 condition ($\beta = 18.15$, SE = 6.99, $z = 2.6$, $p = .047$), but not for the unambiguous conditions ($\beta = -4.09$, SE = 6.91, $z = -.59$, $p = .934$). See Table 2 for model output.

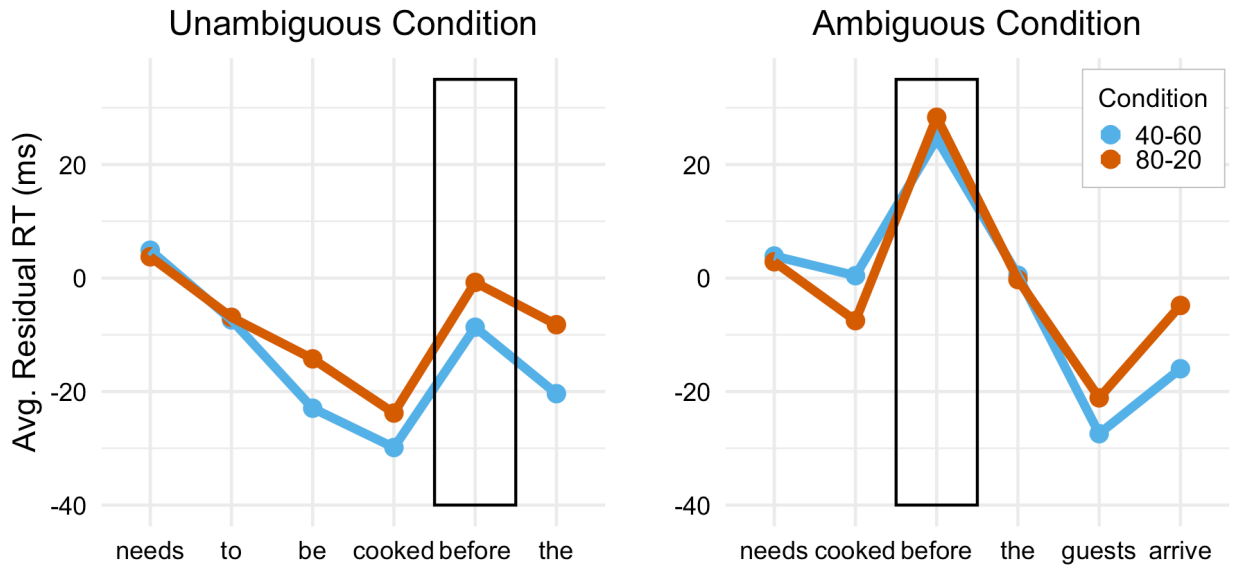

Figure 2. Experiment 1 average residual reading time for **all** target *needs* structures, broken down by distribution and ambiguity condition. The critical word is two words after *needs* (e.g. *before*).

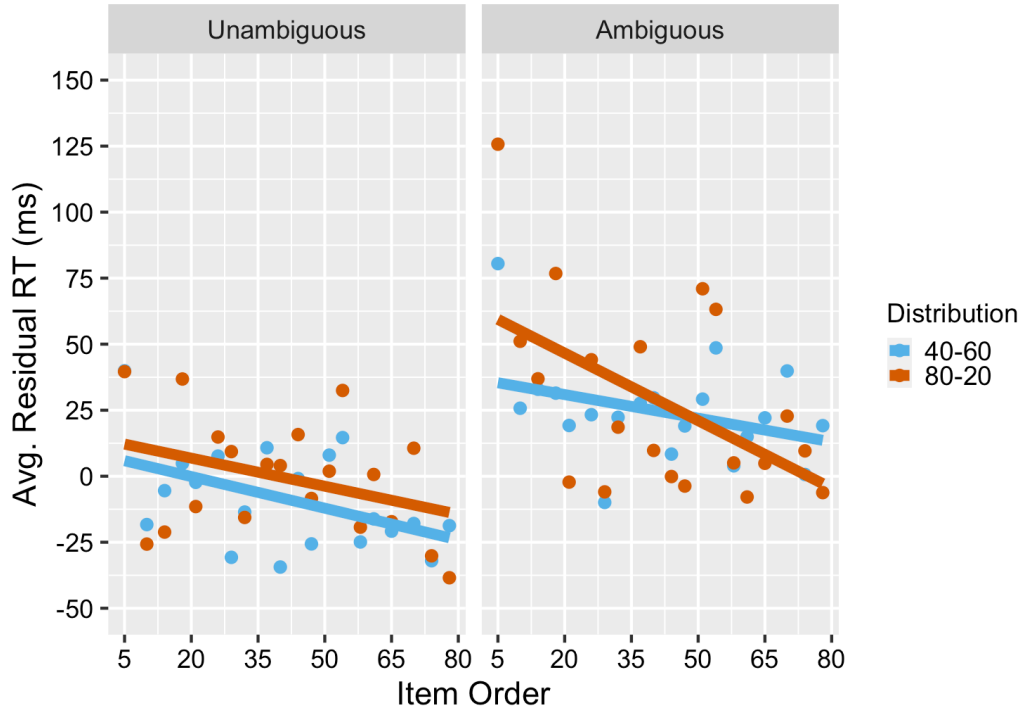

Figure 3. Average residual reading time during the critical word over the course of Experiment 1, broken down by distribution and ambiguity condition.

Table 2. Model output from Experiment 1 for the critical word

Model Parameters	Estimate	*SE*	*t*-value	*p*-value
Intercept	10.55	4.40	2.40	.024
Distribution (80-20 vs. 40-60)	5.52	5.23	1.06	.292
log Item Order	-17.12	5.55	-3.09	.006
Ambiguity (Ambiguous vs. Unambiguous)	31.08	5.23	5.95	< .001
Distribution*log Item Order	-7.03	4.91	-1.43	.152
Distribution*Ambiguity	-4.38	10.46	-.42	.676
log Item Order*Ambiguity	-10.74	4.91	-2.19	.029
Distribution*Ambiguity*log Item Order	-22.24	9.83	-2.26	.024

The reference condition for distribution is 40-60, and the reference condition for ambiguity is the unambiguous condition.

Secondary analyses

Spillover effects. In the self-paced reading task, reaction time is taken to reflect processing time. However, participants may not fully process the critical word until a few words after, leading to delayed effects that occur after disambiguation. Due to the nature of this task and work on self-paced reading suggesting that effects may spill over, secondary analyses were included to investigate whether any effects extended to subsequent words. To test this, residual reading times were analyzed for the three words after the critical word (e.g. *the guests arrive*). A model was constructed for each word, with residual reading time regressed on the same primary predictors.

Other than the three-way interaction, effects on the word after the critical word were largely similar to effects found on the critical word. There was main effect of ambiguity in the model for word 1 ($\beta = 14.12$, SE = 4.56, $t = 3.09$, $p < .01$), as well as a main effect of log item order ($\beta = -8.57$, SE = 2.676, $t = -3.20$, $p < .01$). In contrast to the analysis on the critical word, there was a significant two-way interaction between distribution and log item order ($\beta = -9.05$, SE = 3.70, $t = -2.45$, $p = .014$). Reading times for word 1 were faster for the 80-20 distribution relative to the 40-60 distribution over the course of the experiment, across both ambiguity

conditions (Figure 4). However, like with the critical word, there was no main effect of distribution. For word 2, there was no effect of ambiguity, log item order, or any significant interactions. However, there was a marginal effect of distribution (β = 7.07, SE = 3.76, t = 1.88, p = .061). Similarly, the same marginal effect of distribution is present for word 3 (β = 6.82, SE = 3.65, t = 1.87, p = .063). For these three words after the critical word, there was no significant three-way interaction between the primary predictors. Overall, this suggests that by word 2 & 3, effects from the critical word have washed out.

Figure 4. Average residual reading time during word 1 over the course of Experiment 1, broken down by distribution and ambiguity condition.

Effect of age. A secondary question was whether all participants would respond to the exposure manipulation equally regardless of their age. Older adults have been shown to have higher levels of crystallized intelligence and lower levels of fluid intelligence compared to

younger adults (Horn & Cattell, 1967). This suggests that older participants may not be as sensitive to the manipulation relative to younger participants, and as a result, may not adapt as quickly. To test whether age had any effect on learning the dialectal *needs* sentences, age group was included in the final model with the other primary predictors. Since the key prediction was whether order would interact with distribution, interactions between age and the primary predictors were also added. Due to the diverse participant pool from Amazon Mechanical Turk, there was a wide range of ages in the data (M = 39.85, SD = 12.21, range: 21 to 71 years old). Participants were divided into two groups; any participant who was below the median age (37 years old) was categorized as a young adult, while anyone above was categorized as an older adult. Age group was then contrast-coded and added to the final model, with younger adults as -.5 and older adults as +.5. Results from this model showed no main effect of age group on residual reading times (β = 1.07, SE = 5.27, t = .20, p = .84). There was four-way interaction between distribution, ambiguity, log item order, and age group (β = 69.49, SE = 19.69, t = 3.53, p < .001). There was a difference in residual reading rate for the two distributions in the ambiguous condition for only the younger participants (β = 31.31, SE = 9.62, t = 3.25, p = .025), but not the older participants (β = 12.39, SE = 10.17, t = 1.22, p = .926, Figure 5).

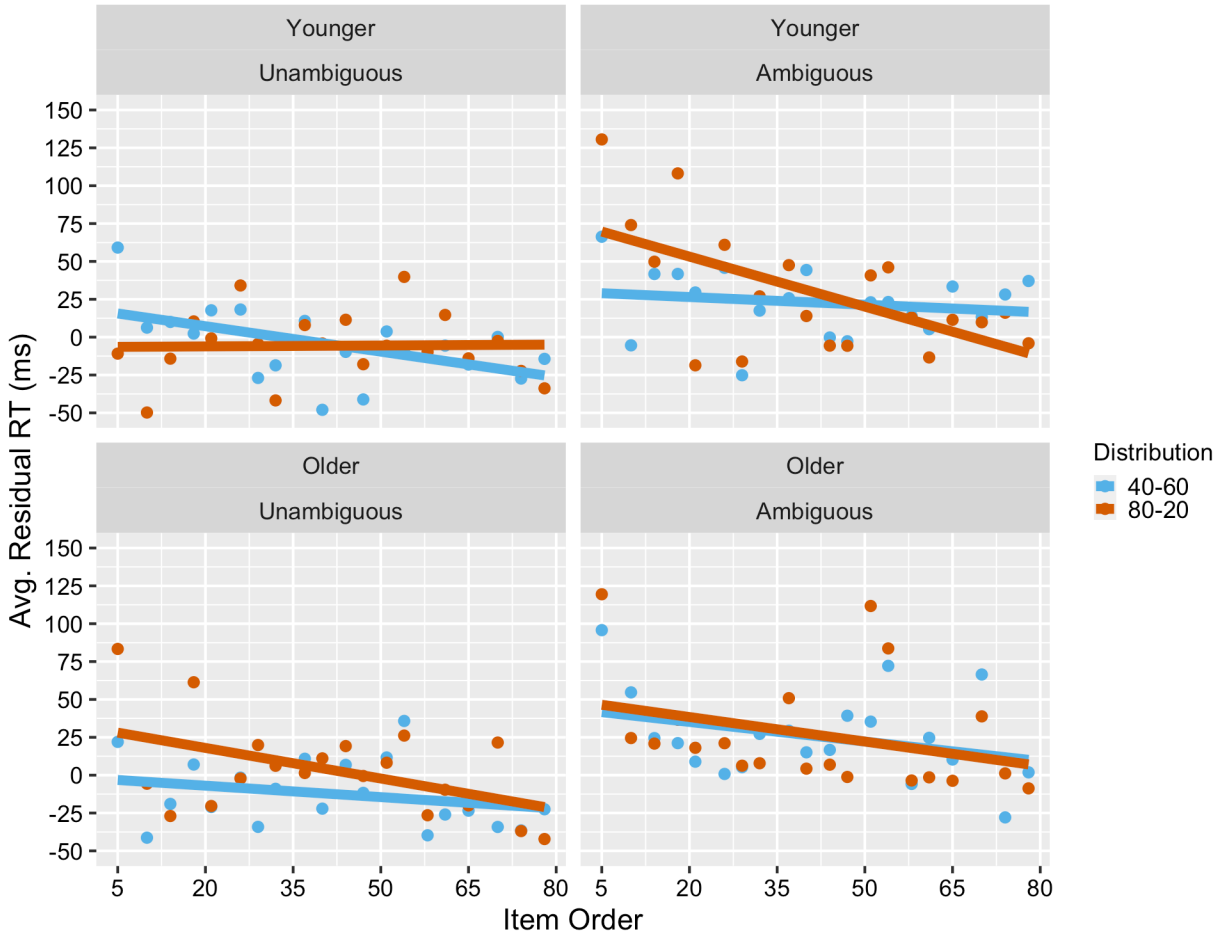

Figure 5. Average residual reading time during the critical word over the course of Experiment 1, separated by distribution, ambiguity condition, and age group. Participant age was divided into two groups based on the median (< 37: Younger, ≥ 37: Older).

Experiment 1 discussion

The findings from Experiment 1 suggest that not only can participants rapidly adapt to this unfamiliar dialectal structure, but that this is modulated by relative frequency. Participants in the ambiguous condition read the dialectal sentences slower than those reading the standard sentences. However, they adapted to the dialectal sentences at a faster rate, which replicates the results from Kaschak & Glenberg (2004). Importantly, as participants were exposed to the

distribution, the rate of adaptation to the dialectal sentences differed between the two distributions. A higher proportion of the unfamiliar, dialectal *needs* structure led to a faster rate of adaptation compared to a lower proportion.

The findings from Experiment 1 provide causal evidence that relative frequency plays a role in syntactic processing, independent of exposure. This is critical as theoretical models of syntactic processing (e.g. MacDonald et al., 1994) emphasize relative frequency to explain processing difficulty in comprehension. This also replicates findings on syntactic adaptation (e.g. Fine et al., 2013), in which increased exposure to infrequent structures results to less processing difficulty over time. In addition, the ability to adapt to the dialectal structure shows that people can form syntactic representations of this new structure despite the sentence sounding ungrammatical, consistent with Ivanova et al. (2012).

Secondary analyses show that the critical three-way interaction did not spill over to subsequent words. Although there were multiple main effects and significant interactions in the three following words, these effects can only be interpreted with caution as they occur after disambiguation. For example, at word 1, participants read the target *needs* sentences faster in the 80-20 distribution compared to the 40-60 distribution. This possibly suggests that at this word, distribution is playing a role even for the unambiguous condition. This finding raises questions about when during the sentence distribution affects processing, and whether alternative structures act as competition even once the sentence has been disambiguated. Future work will have to explore these ideas.

Similarly, a secondary analysis revealed that participant age interacted with all three primary predictors in a four-way interaction. Younger participants adapted to the distribution manipulation in the ambiguous condition, while older participants did not. Although this finding

has implications on learning, the primary goal of this experiment was not to test for effects of participant age. Future work is needed to better address the effect of age on learning, and to confirm whether the four-way interaction found in this experiment holds.

The findings from Experiment 1 raise further questions about what can be learned from experience with these syntactic structures. The first is whether participants can track differences in relative frequency even when the dialectal structure is in the majority for both distributions, and the second is whether participants can generalize distributional information on a verb-general level. Both of these questions are followed up in Experiment 2 and 3.

CHAPTER 3: TEST OF FINE-GRAINED PROBABILISTIC KNOWLEDGE

Experiment 1 found an effect of relative frequency on rate of adaptation, over and above raw frequency. Experiment 2 directly follows up on Experiment 1 by investigating whether there is sensitivity to distributional differences even when the dialectal structure is in the majority for both distributions. To test this, the same design was used as in Experiment 1, however the distributions varied slightly. In Experiment 2, participants were exposed to either a 90-10 distribution or a 66-33 distribution. In both cases, the proportion of dialectal structures was higher relative to the modifier structures, and the same 20 dialectal sentences were used as in Experiment 1. The only change was that there were less modifier sentences and more unrelated filler sentences in both distributions.

Experiment 2

Motivation

Experiment 2 tests whether people can detect differences between structures where one is slightly higher in relative frequency compared to the other. Probabilistic models of syntactic comprehension assume ranking of probable structures; the conditional probability of a structure is calculated given previous input, and these probabilities are ranked in order to select the best possible parse (e.g. Jurafsky, 1996). Therefore, if expectations are based on the conditional probability of each structure, comprehenders need to know these specific probabilities in order to rank them. In contrast, it is possible that comprehenders may only be sensitive to the structure that is the frequent alternative, and only keep track of rough estimates of frequency statistics. The objective of Experiment 2 is to test whether people categorize syntactic structures into high

probability vs. low probability, or if they can detect fine-grained differences in syntactic probabilities.

Methods

Participants

353 participants were recruited from Amazon Mechanical Turk, and received $2.00 in exchange for completing the study. Experiment 2 used the same exclusion criterion as in Experiment 1; participants must be a native English speaker and not overly familiar with sentences like *the car needs washed* prior to the experiment. 40 participants were excluded for not meeting this criterion. This left a total of 313 participants.

Materials and design

Experiment 2 had the same design as Experiment 1: a 2 x 2 between-subjects design with two distributions (90-10 vs. 66-33) and an ambiguous and unambiguous condition. As with Experiment 1, the proportion of the dialectal *needs* and standard *needs* structures was manipulated across two distributions. Participants were assigned to 1 of 4 lists, in which the number of dialectal/standard *needs* structures stayed constant, but the number of modifiers varied to match the target distribution at any given point throughout the experiment. Therefore, in the 66-33 distribution, participants read 20 dialectal *needs* structures and 10 modifier structures. In the more extreme condition, the 90-10 distribution, participants read 20 needs structures and 2 modifier structures. Critically, exposure to the dialectal/standard *needs* sentences is kept constant in order to investigate the effects of distribution independent of exposure.

As with Experiment 1, the number of unrelated fillers changed depending on the distribution. The fillers used in the current study do not overlap in word or syntactic structure, therefore they are unlikely to affect reading times for the dialectal *needs* sentences. On the other

hand, if the number of unrelated fillers were kept constant across distribution, it would introduce a confound; the effect of distribution would be confounded with task adaptation. See Figure 6 for a model of how the sentences are ordered across the experiment. Stimuli for Experiment 2 are in Appendix B.

Table 3. Number of each sentence type for each condition for Experiment 2.

	90-10	**66-33**
Ambiguous	20 dialectal *needs* 2 modifiers 58 fillers	20 dialectal *needs* 10 modifiers 50 fillers
Unambiguous	20 standard *needs* 2 modifiers 58 fillers	20 standard *needs* 10 modifiers 50 fillers

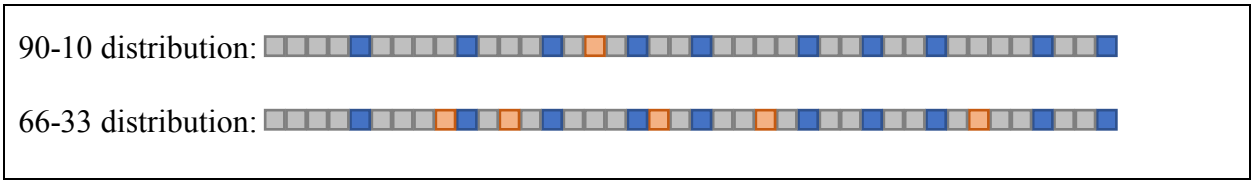

Figure 6. A representation of the order that sentences are presented in for each distribution, for the first half of Experiment 2. Blue squares represent the dialectal/standard sentences, orange squares represent modifier sentences, and gray squares represent unrelated filler sentences.

Procedure

The procedure was identical to Experiment 1. Participants read sentences in a self-paced moving window display one word at a time, and answered one comprehension question after reaching the end of the sentence.

Analytic approach

The same analytic approach was used as in Experiment 1.

Data Processing and exclusions

The same exclusion criterion was used as in Experiment 1. Raw reading times that were very short (< 100ms) or were longer than two times the standard deviation above the mean were excluded from analysis. This affected 1.07% of the data. Trials where the comprehension question was answered incorrectly were also excluded, which affected 3.68% of the data.

Results

Primary analysis

To test whether there was a difference in reading time between the 90-10 distribution and the 66-33 distribution, the target needs structures were analyzed at the disambiguating word. As with Experiment 1, the same word was analyzed in both the ambiguous and unambiguous conditions. On average, participants were faster at reading the critical word in the standard sentences relative to the dialectal sentences. This emerged as a main effect of ambiguity in the model; there was a significant effect of ambiguity condition on residual reading times ($\beta = 36.49$, $SE = 4.78$, $t = 7.63$, $p < .001$, Figure 7). This replicates the results from Experiment 1; participants unfamiliar with the dialectal sentence read the dialectal sentences slower, compared to participants reading the standard sentences. There was also a main effect of log item order ($\beta = -19.89$, $SE = 5.03$, $t = -3.96$, $p < .001$), indicating that there was overall syntactic adaptation. There was also a significant two-way interaction between log item order and ambiguity ($\beta = -13.59$, $SE = 4.96$, $t = -2.73$, $p < .01$); participants adapted at a faster rate to the dialectal sentences in the ambiguous condition than the unambiguous condition.

The primary question of Experiment 3 was whether participants were sensitive to the probability that the structure occurred at within the linguistic environment, or if they could only keep track of which structure was frequent relative to alternative structures. Over the course of

the experiment, there was no difference between the two distributions; participants in the ambiguous condition read the critical word at the same rate in the 90-10 distribution as in the 66-33 distribution (Figure 8). There was no interaction between distribution, ambiguity, and log item order (β = 11.54, SE = 9.92, t = 1.16, p = .245). There was no difference in the rate of residual reading times between the 90-10 and 66-33 distribution for either the ambiguous (β = -5.37, SE = 7.07, z = -.76, p = .873) or unambiguous condition. (β = 6.18, SE = 6.97, z = .89, p = .812). See Table 4 for full model output.

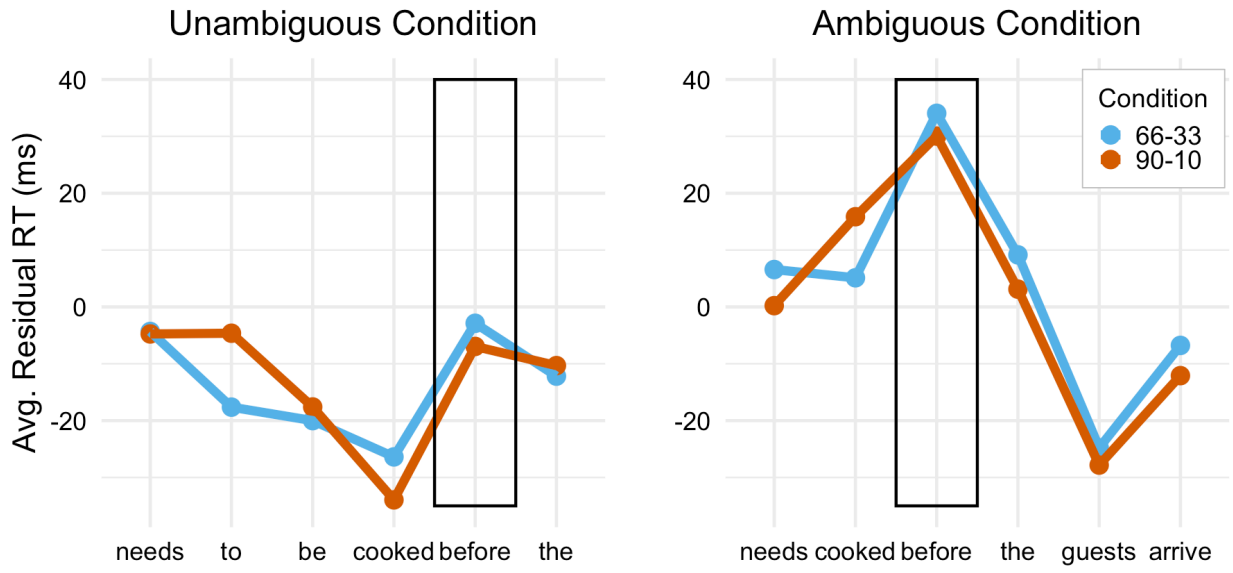

Figure 7. Experiment 2 average residual reading time for **all** target *needs* structures, broken down by distribution and ambiguity condition. The critical word is two words after *needs* (e.g. *before*).

Figure 8. Average residual reading time during the critical word over the course of Experiment 2, broken down by distribution and ambiguity condition.

Table 4. Model output from Experiment 2 for the critical word

Model Parameters	Estimate	*SE*	*t*-value	*p*-value
Intercept	13.38	3.92	3.41	.002
Distribution (90-10 vs. 66-33)	-3.93	4.78	-0.82	.412
log Item Order	-19.9	5.03	-3.96	< .001
Ambiguity (Ambiguous vs. Unambiguous)	36.49	4.78	7.63	< .001
Distribution*log Item Order	-.41	4.96	-.08	.935
Distribution*Ambiguity	.05	9.56	.01	.996
log Item Order*Ambiguity	-13.59	4.96	-2.74	.006
Distribution*Ambiguity*log Item Order	11.54	9.92	1.16	.245

The reference condition for distribution is 66-33, and the reference condition for ambiguity is the unambiguous condition.

Secondary analyses

Spillover regions. As with Experiment 1, residual reading times were analyzed for the

three words after the critical word (e.g. *the guests arrive*). For word 1, there was only a main effect of ambiguity (β = 16.97, SE = 34.78, t = 3.55, p < .001), and a main effect of log item order (β = -8.99, SE = 3.99, t = -2.26, p = .037). For word 2, there were no significant main effects or interactions. Lastly, for word 3, there was a marginal interaction between distribution and log item order (β = -7.58, SE = 4.18, t = -1.82, p = .07), and a significant three-way interaction between distribution, ambiguity, and log item order (β = 17.35, SE = 8.36, t = 2.08, p = .038). Probing this interaction revealed a difference in the rate of residual reading times between the 90-10 and 66-33 distribution for the unambiguous (β = 16.26, SE = 5.87, z = 2.76, p = .029) but not the ambiguous condition (β = -1.09, SE = 5.95, z = -.18, p = .998). The direction of the three-way interaction is different from expected, with reading rate increasing over the course of the 66-33 distribution in only the unambiguous condition (Figure 8).

Figure 9. Average residual reading time during word 3 over the course of Experiment 2, broken down by distribution and ambiguity condition.

Effect of age. As with Experiment 1, participant age was included as a predictor in the model to test whether all participants would respond to the exposure manipulation equally. Participants (M = 42.37, SD = 13.82, range: 21 to 78 years old) were divided into two groups by median-split (38 years old). Participants below the median age were categorized as a young adult, while anyone above was categorized as an older adult. Age group was then contrast-coded and added to a control model, with younger adults as -.5 and older adults as +.5. When participant age was added to the final model with the primary predictors, there was neither a main effect nor significant interaction with age.

Post-hoc analysis

The findings from the primary analysis raise the question of whether reading times in either the 90-10 or the 66-33 distribution were different from the 40-60 distribution in Experiment 1. Since the 90-10 and 66-33 distribution both have a higher relative frequency of the dialectal structure, the rate of adaptation should differ from a distribution with a lower relative frequency of the same structure. Therefore, to test this, both the 90-10 and 66-33 distributions were compared to the 40-60 distribution from Experiment 1 in separate, post-hoc analyses. Performing these analyses allows for comparison between a distribution with a lower proportion of the dialectal structure with the two high proportion distributions in this experiment. However, it is important to note that the number of participants are unbalanced: there is a difference of around 100 participants between Experiment 1 and 2. Therefore, any results reported in this analysis needs to be followed up with a separate experiment.

Data collected from Experiment 1 & 2 were combined with the purpose of comparing between 90-10 and 40-60, and 66-33 with 40-60. Separate linear-mixed effects models were conducted on these two comparisons, using the same model building procedure as Experiment 1

and 2. Surprisingly, there was no difference between the 90-10 and 40-60 distributions, despite a numerical trend (Figure 9). There was no interaction between distribution (90-10 vs. 40-60), ambiguity, and log item order (β = -8.09, SE = 9.6, t = -0.84, p = .399). There was no difference in the rate of residual reading times between the 90-10 and 40-60 distribution for the ambiguous (β = 10.43, SE = 6.87, z = 1.52, p = .43). When comparing the 66-33 distribution with the 40-60 distribution, there was a marginally significant interaction between distribution (66-33 vs. 40-60), ambiguity, and log item order (β = -19.68, SE = 10.2, t = -1.93, p = .05). However, when probing the interaction, there was no significant difference between the distributions in the ambiguous condition (β = 15.83, SE = 7.27, z = 2.18, p = .129).

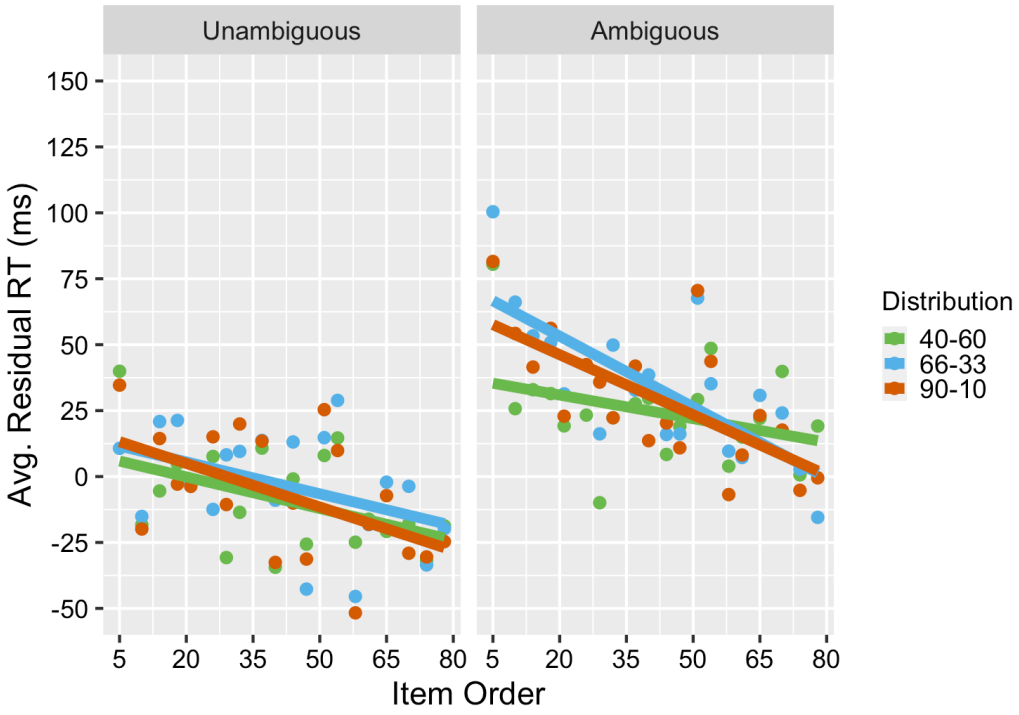

Figure 10. Average residual reading time during the critical word over the course of the experiment, broken down by all distributions and ambiguity condition.

Experiment 2 discussion

Experiment 2 found no difference in the rate of adaptation between the 90-10 distribution and the 66-33 distribution. The lack of a significant interaction between the primary predictors indicates that participants adapted to the unfamiliar dialectal sentences similarly for both distributions, despite the 90-10 distribution having a higher relative frequency of the dialectal sentences compared to the 66-33 distribution.

The results from Experiment 2 replicate the finding that participants are slower at reading the dialectal sentences, and adapt faster to them relative to the standard sentences. However, unlike in Experiment 1, there was no effect of distribution in the ambiguous condition. This suggests that in contrast to models that predict fine-grain probability tracking (e.g. Jurafsky, 1996), participants may only be keeping track of the more frequent alternative. In other words, it is possible that there may be a certain probability threshold a structure must reach in order for it to be considered frequent. In Experiment 2, there was only a difference of 8 modifiers between the two distributions. In contrast, the distributions in Experiment 1 had a difference of 25 modifier sentences. The difference in the number of modifiers in Experiment 2 may have not been enough to find any distinctions between the two distributions.

A post-hoc analysis comparing the 40-60 distribution and both the 90-10 and 66-33 distribution revealed no significant differences between these distributions. This is surprising as numerically the trend looks almost identical to the two distributions in Experiment 1. The lack of interaction may be due to the imbalance in participants between the two experiments; there were only 116 participants in the 40-60 condition, while there were around 160 each in the 90-10 and 66-33 conditions. To properly confirm the results from Experiment 1, an additional follow-up

experiment will need to collect data from the same number of participants as in the 90-10 and 66-33 distributions.

To test whether the critical three-way interaction could have spilled over to subsequent words, secondary analyses were performed on the three words following disambiguation. These analyses revealed a significant three-way interaction during word 3; participants in the 66-33 distribution read word 3 more slowly over the course of the experiment compared to the 90-10 distribution, but this only happened for the standard *needs* sentences. Similar to the interaction found at word 1 in Experiment 1, this suggests that distribution is playing a role even for the unambiguous condition, which was not expected. Future work will have to investigate the time course of these effects, in addition to the effect of competing structures on processing after disambiguation.

CHAPTER 4: TEST OF GENERALIZATION

The results from Experiment 1 imply that people are sensitive to the distributional changes, as shown by the difference in the adaptation rate across the two conditions over and above exposure. Experiment 3 builds on this finding by testing whether the distributional information associated with the verb *needs* can be generalized to a similar verb, *wants*. To test this, the same distributions were used as in Experiment 1 (80-20 vs. 40-60), however the experiment was divided into an exposure phase and a test phase. During the exposure phase, participants were either trained on dialectal *needs* sentences or dialectal *wants* sentences. During test, all participants received the dialectal *wants* sentences. If there is an effect of relative frequency on the test sentence for participants who trained on the dialectal *needs* sentences, it suggests that comprehenders can generalize frequency information to other verbs. If the effect of distribution only occurs for the *wants*-training condition, it suggests that comprehenders could not generalize.

Experiment 3

Motivation

Previous research has shown that overall exposure to the dialectal *needs* structures can facilitate processing of the same structure but with a different verb (e.g. *wants*; Kaschak & Glenberg 2004), which implies that exposure to a structure creates an abstract, syntactic representation that is not only tied to one lexical item. This raises the question of whether the relative frequency of a structure can also be generalized across verbs. If frequency information does generalize, then this would reduce comprehenders' computational burden, as they would

only have to track frequency information on the structural level instead of every lexical item encountered. If distributional information is verb-specific, then frequency information may be stored separately for each individual verb. Experiment 3 investigates whether the distribution of the dialectal *needs* and modifier structures can be applied to the verb *wants* in the same dialectal structure.

Methods

Participants

384 participants were recruited from Amazon Mechanical Turk, and received $2.00 in exchange for completing the study. Experiment 3 used the same exclusion criterion as in Experiment 1; participants had to be a native English speaker and not overly familiar with sentences like *the car needs washed* prior to the experiment. 16 participants were excluded for not meeting this criterion. This left a total of 331 participants.

Materials and design

Experiment 3 used the same target and competing syntactic structures as in Experiment 1. However, to control for animacy across items, sentences were modified so that the first noun phrase in every dialectal and modifier structure was animate.

Experiment 3 was a 2 x 2 between-subjects design with two distributions and two training conditions, each with a different verb (dialectal *needs* vs. dialectal *wants*). Unlike Experiment 1, Experiment 3 was divided into an exposure phase and a test phase (Table 5). The test phase was the same for all participants. In the test phase, participants read sentences in the same structure as the dialectal *needs* structures, but using a different verb (e.g. *The dog <u>wants</u> washed*). The test phase is preceded by the exposure phase, where participants were trained either on dialectal *needs* or dialectal *wants* sentences. As in Experiment 1, the distribution of the exposure phase

was either 80-20 or 40-60 (Figure 10). In the dialectal *needs* training, participants were exposed to 20 dialectal *needs* sentences (e.g. *The dog needs washed*, instead of *The dog needs to be washed*) and a specific number of modifier sentences (e.g. *The dog needs washed toys*) depending on whether the distribution was 80-20 or 40-60. Similarly, in the dialectal *wants* training, participants were exposed to 20 dialectal *wants* sentences (e.g. *The dog wants washed*, instead of *The dog wants to be washed*), along with the competing modifier sentences (e.g. *The dog wants washed toys*). Importantly, the dialectal structure was always ambiguous with the competing modifier structure. This design led to four lists: an 80-20 distribution with dialectal *needs* training, a 40-60 distribution with dialectal *needs* training, an 80-20 distribution with dialectal *wants* training, and a 40-60 distribution with dialectal *wants* training.

Table 5. Number of each sentence type for each condition in the exposure and test phases for Experiment 3.

	80-20	**40-60**	**80-20**	**40-60**
Exposure Phase	20 dialectal *needs* 5 modifiers 55 unrelated	20 dialectal *needs* 30 modifiers 30 unrelated	20 dialectal *wants* 5 modifiers 55 unrelated	20 dialectal *wants* 30 modifiers 30 unrelated
Test Phase	10 dialectal *wants* 20 unrelated			

Exposure Phase

Needs Training

80-20 distribution: 

40-60 distribution: 

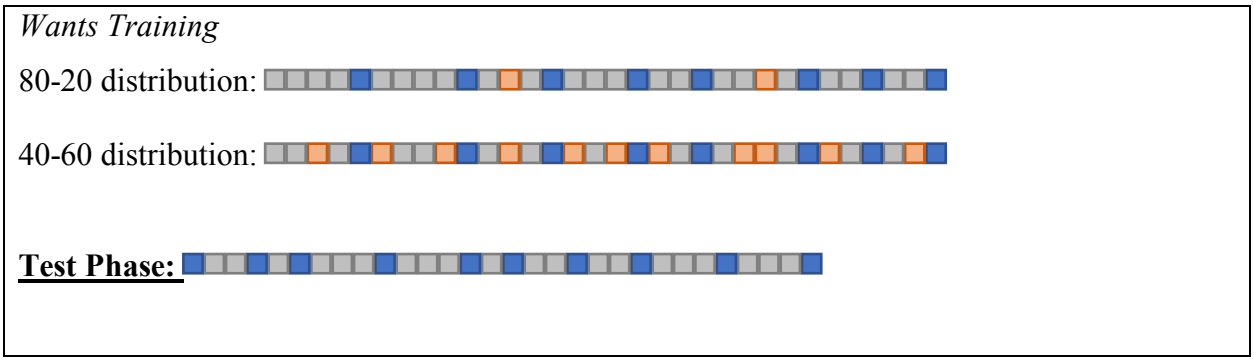

Figure 11. A representation of the order that sentences are presented in for each distribution and each training type, for the first half of Experiment 3. Green squares represent the dialectal *needs* sentences, blue squares represent the dialectal *wants* sentences, orange squares represent modifier sentences, and gray squares represent unrelated filler sentences.

After the exposure phase, participants transitioned to the test phase. Participants read 10 dialectal *wants* sentences interleaved with 20 unrelated filler sentences. To minimize learning from the test phase, the number of test sentences was limited to 10. The stimuli for Experiment 3 are in Appendix C.

Procedure

The same procedure was used as in Experiment 1.

Analytic approach

Residual reading times were analyzed at disambiguation (two words after *needs* or *wants*) in a linear mixed-effects modeling framework. The average residual reading time in the test phase was compared across conditions. The primary predictors in the model were distribution and training condition (*wants* vs. *needs*). Distribution was contrast-coded, with the 80-20 distribution as +.5 and the 40-60 distribution as -.5. The *needs* training condition was coded as +.5 while the *wants* training condition was coded as -.5. Item order (log-transformed and grand-mean centered) was included as a control variable. The two-way interaction between distribution

and training condition was included in the model. To further probe the interaction, planned comparisons were used to test whether there were differences between the two distributions for each training type. The *p*-values for all pairwise comparisons were adjusted using Tukey's method. Models included random intercepts for both item and participant. Random slopes were not included because they either caused the model to not converge or were estimated to be zero.

Data Processing and exclusions

The same exclusion criterion was used as in Experiment 1. Raw reading times that were very short (< 100ms) or were longer than two times the standard deviation above the mean were excluded from analysis. This affected 3.37% of the data. Trials where the comprehension question was answered incorrectly were also excluded, which affected 5.77% of the data.

To keep the dependent variable consistent across experiments, the same data processing procedure was used as in Experiment 1.

Results

Primary analysis

The dialectal *wants* sentences in the test phase were analyzed at the disambiguating word. Across the *needs* and *wants* training conditions, there was a numerical difference between the 80-20 and 40-60 distribution. However, this did not emerge as a significant main effect in the model (β = -4.76, SE = 7.64, t = -.62, p = .534). In contrast, there was a main effect of training condition. Participants were faster at reading the critical word after being exposed to the dialectal *needs* sentences than the participants trained on the dialectal *wants* sentences (β = -17.36, SE = 7.64, t = -2.27, p = .024, Figure 11, 12).

The primary question of Experiment 3 was whether the distribution could be generalized to a different verb but within the same dialectal structure. The two-way interaction between

distribution and training condition was not significant (β = 2.76, SE = 15.27, t = .18, p = .857), indicating no difference between the two training conditions when comparing the difference in distribution. Within each training condition, distribution did not have an effect. In the dialectal *needs* training condition, residual reading times for the critical word were not significantly different for the 80-20 distribution than the 40-60 distribution (β = 3.38, SE = 10.8, t = .31, p = .989). Likewise, in the dialectal *wants* training condition, there was no difference between the two distributions (β = 6.11, SE = 10.8, t = .57, p = .942). See Table 6 for full model output.

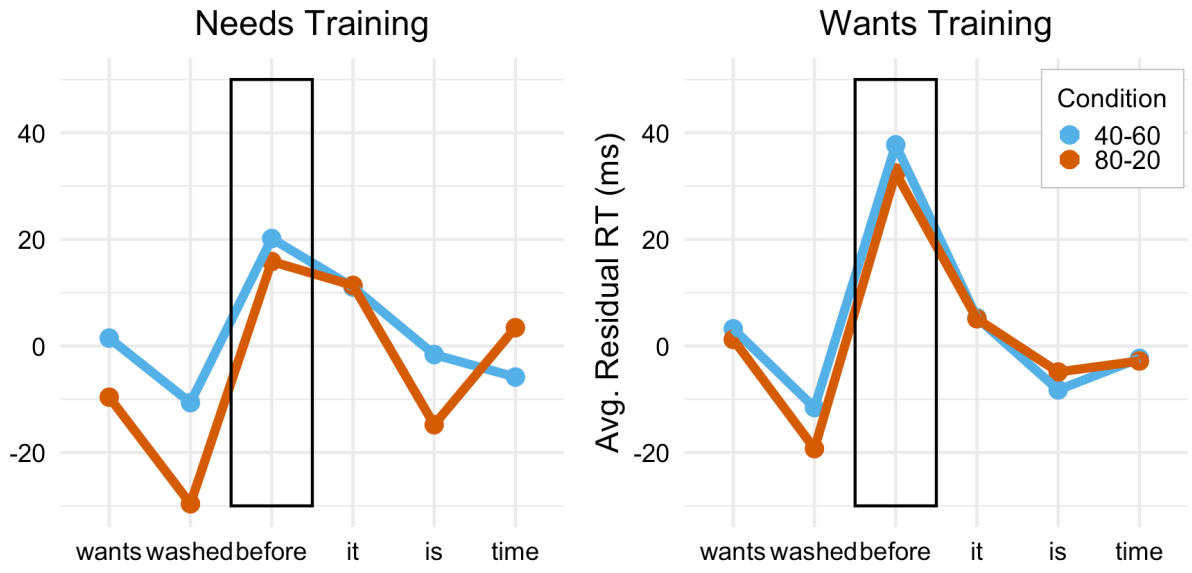

Figure 12. Experiment 3 average residual reading time for target *wants* structures during the test phase, broken down by distribution and ambiguity condition. The critical word is two words after *wants*.

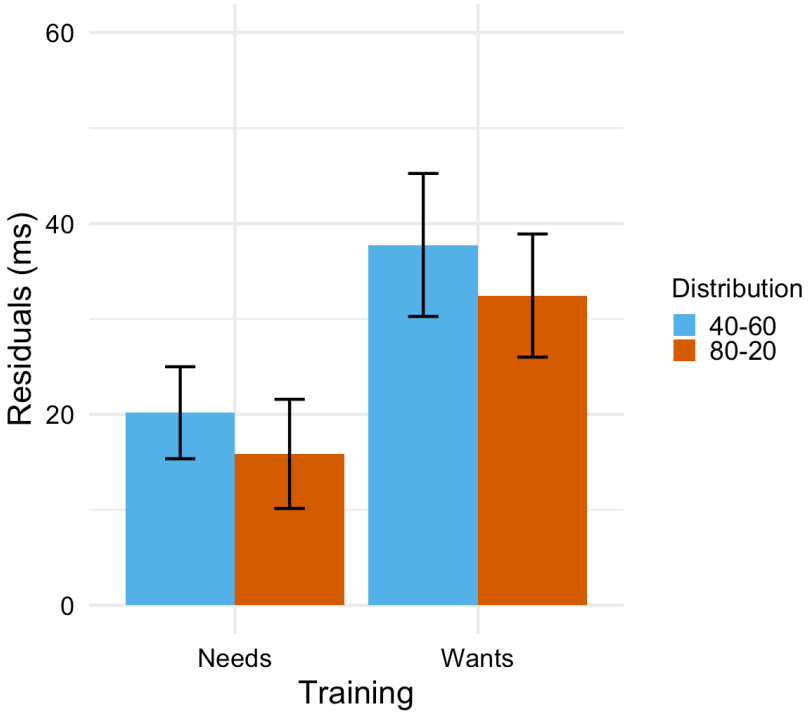

Figure 13. Experiment 3 average residual reading time during the critical word, broken down by distribution and ambiguity condition. Error bars represent within-subject SEs.

Table 6. Model output from Experiment 3 for the critical word

Model Parameters	Estimate	*SE*	*t*-value	*p*-value
(Intercept)	26.12	7.16	3.65	.004
Distribution (80-20 vs. 40-60)	-4.76	7.64	-.62	.534
Training: n*eeds* vs. *wants*	-17.36	7.64	-2.27	.024
log Item Order	39.76	69.13	.58	.581
Distribution*Training	2.76	15.27	.18	.857

The reference condition for distribution is 40-60, and the reference condition for training is the dialectal *wants* training condition.

Secondary analyses

Spillover region. Similar to previous experiments, subsequent words in the dialectal *wants* sentences were analyzed to test whether any effects spilled over. Residual reading times were analyzed for the three words after the critical word (e.g. *it is time*). A model was

constructed for each word, with residual reading time regressed on the same primary predictors as in the final model. For all three words, there were no significant main effects or interactions.

Effect of age. As with previous experiments, age was included in the model as a secondary analysis to test whether the manipulation affected all participants equally. The same procedure was used as in Experiment 1; participants (M = 39.7, SD = 10.66, range: 19 to 73 years old) were divided into two groups based on the median (median = 37 years old). Age group was then contrast-coded, and added to the final model with primary predictors. Results from this model revealed neither a main effect nor any significant interactions with age.

Interim discussion

The primary purpose of Experiment 3 was to test whether the relative frequency of the dialectal *needs* sentences could affect processing of the dialectal *wants* sentences. However, the effect of distribution did not show up in the statistics, despite a numerical trend. This may be because this effect only shows up as a function of item order right when participants are exposed to the dialectal structure, similar to Experiment 1. It is also possible that there was no effect of the manipulation during the exposure phase. There may be no effect of distribution because participants were not sensitive to the distributional changes during training, and therefore the frequency information was not transferred to the test sentences. To test whether the manipulation worked, residual reading time was analyzed for both the *wants* and *needs* dialectal sentences during the exposure phase. If participants were sensitive to the manipulation in relative frequency, then there should be a difference in the level of adaptation between the two distributions.

Post-hoc analysis

Due to the lack of effect in distribution on residual reading time, a post-hoc analysis was

conducted on both the *wants* and *needs* dialectal sentences in the exposure phase. If participants adapted differently based on the distribution, there should be a difference in reading rate between the 80-20 and 40-60 distributions, over the course of the exposure phase. A similar model-building procedure was used as in Experiment 1; residual reading time was analyzed at the critical word with distribution, training condition, and log item order as predictors. The model revealed a significant main effect of log item order (β = -40.95, SE = 5.17, t = -7.93, p = < .001), and a significant interaction between distribution and log item order (β = -21.63, SE = 5.17, t = -7.93, p < .001). There was also a marginal three-way interaction between distribution, training condition, and log item order (β = -22.17, SE = 12.3, t = -1.8, p = .072). When probing the interaction, reading times for the critical word decreased faster in the 80-20 condition than the 40-60 condition for the dialectal *needs* training condition (β = 32.72, SE = 8.7, z = 3.76, p = .001), but not for the dialectal *wants* training condition (β = 10.55, SE = 8.69, z = 1.21, p = .618, Figure 13).

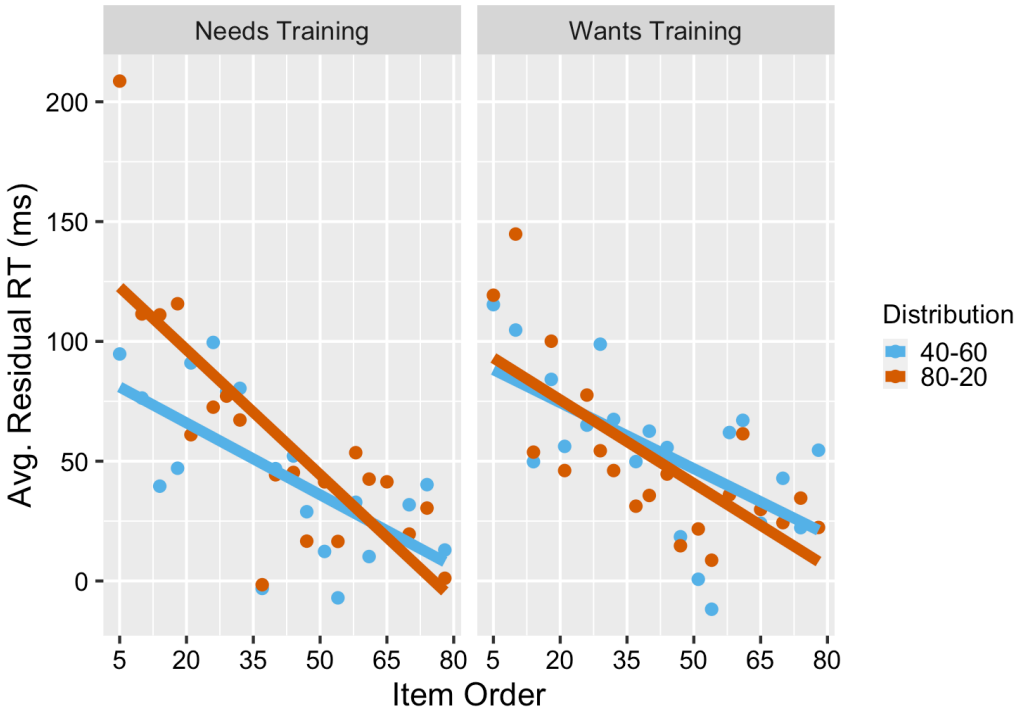

Figure 14. Average residual reading time during the critical word over the course of the exposure phase, broken down by distribution and training condition.

Experiment 3 discussion

The main finding from Experiment 3 is that there was no main effect of distribution. A further analysis showed that there was a difference in adaptation rate between the two distributions in the dialectal *needs* training condition, but not the dialectal *wants* training condition. This raises some concern, because though this finding replicates Experiment 1, it only does so for the dialectal *needs* sentences. Furthermore, the three-way interaction is driven by the long residual reading times in the first trial in the dialectal *needs* training condition.

One difference between Experiment 1 & 3 that may have led to this inconsistency is the change in stimuli. In Experiment 3, sentences were created to work for 1) both the verb *needs* and *wants,* and 2) to be ambiguous between the dialectal and modifier structure until disambiguation. This led to some constraints that were not present in Experiment 1; the verb *wants* usually requires an animate subject argument (i.e. *The dog wants washed, *The car wants washed*), while *needs* does not (i.e. *The car needs washed*). To be ambiguous between the two structures, the past participle must be able to modifier the animate subject, in addition to the following noun (i.e. *The academics want trained on new methodology vs. The academics want trained research assistants*). For example, if someone received the fragment *The chef wants cooked…,* it is not likely that this sentence will continue as the dialectal sentence because people usually are not cooked. Although great care was taken to create test sentences that were fully ambiguous between the dialectal and modifier structure up until disambiguation, biases may have emerged as early as the first word in the sentence. This may have led to differences between

the dialectal *needs* sentences in Experiment 1, and the dialectal sentences in the current experiment.

The surprising finding from Experiment 3 is that participants in the *needs* training condition read the test sentences faster than the participants trained on the same sentences they were tested on. One potential explanation for this result may be due to the presence of modifiers that use the verb *wants.* In the dialectal *needs* training condition, participants are only exposed to modifier sentences that use the verb *needs,* but they do not encounter the modifier *wants* sentences in the test phase. In contrast, the modifier *wants* sentences in the dialectal *wants* training condition act as competition to the dialectal *wants* sentences. Participants' experience with the modifier *wants* sentences in the exposure phase may have caused a slowdown during the test phase. In the dialectal *needs* training condition, there may be no reason for participants to apply the distribution from the dialectal *needs* to the dialectal *wants*, because participants did not encounter any competition with that particular verb. This would possibly suggest a model where the underlying syntactic structure is generalized across verbs, but information on competing structures is verb-specific and does not transfer.

The above explanation could be taken as support for generalization of the dialectal structure. Compared to participants who were trained on the dialectal *wants* sentences, exposure to the dialectal *needs* sentences facilitated processing of the test sentences. This is a possibility, because we would expect overall longer reading times if there was no interaction between the dialectal *needs* sentences and the dialectal *wants* sentences. On the other hand, this interpretation should be treated with caution because there is no baseline condition. To confirm whether there is generalization across these two verbs, a follow-up study should compare a dialectal *needs* training condition with a dialectal *wants* training condition that has zero modifier competitor

sentences. If the reading times from the dialectal *needs* condition are comparable to the reading times in the dialectal *wants* condition, then that would not only confirm generalization from dialectal *needs* to dialectal *wants*, but also that information on alternative structures is verb-specific.

The other possibility is that participants in the dialectal *needs* training condition are not generalizing the structure to a new verb, but rather have become satiated to ungrammatical sentences in general. Though this may be the case, there is evidence suggesting that priming does not occur for all ungrammatical structures (Sprouse, 2007), and the magnitude of the priming effect may depend on how acceptable the sentence is to the comprehender (Do & Kaiser, 2017). Priming of ungrammatical sentences has also only been found in structures where the target and the prime sentence are similar in structure (Kaschak & Glenberg, 2004; Ivanova et al., 2012; Luka & Barsalou, 2005). This heavily suggests that in order for adaptation to occur, there needs to be a certain level of syntactic similarity between the target structure and the prime. Therefore, it would be surprising if participants became used to any ungrammatical structure after training on the dialectal structure, though future work would have to test this.

CHAPTER 5: GENERAL DISCUSSION

This project is the first to experimentally test the role of relative frequency on syntactic processing. The main finding from this study is that relative frequency significantly affected the rate of adaptation to an unfamiliar structure, over and above raw frequency. This was found in Experiment 1, where there was a difference in reading time between the 80-20 and 40-60 distributions for only the dialectal *needs* sentences. However, in Experiment 2, when comparing distributions where the dialectal sentences were higher in proportion (90-10 vs. 66-33), this difference disappeared. Lastly, the results from Experiment 3 were mixed. There was no effect of distribution in the test phase, and a further analysis showed that the manipulation did not affect the two training conditions equally. However, participants in the *needs* training condition had significantly faster reading times than those in the *wants* training condition, which raises the possibility that generalization did occur across verbs. Note that Experiment 3 analyzes residual reading time averages during the test phase, while the other two experiments analyze reading time over the course of the experiment.

The findings from Experiment 1 are consistent with correlational studies examining reading time and frequency statistics, and with syntactic adaptation studies. Participants were able to adapt to the unfamiliar dialectal structure after only being exposed to 20 dialectal sentences, replicating Kaschak & Glenberg (2004) and Fraundorf & Jaeger (2016). This is also in line with work showing priming of ungrammatical structures (e.g. Ivanova et al. 2012). Importantly, the results from Experiment 1 provide direct, causal evidence in support of

experience-based models where relative frequency plays a role in processing. It suggests that people are sensitive to relative frequency independent of overall exposure.

By comparison, there was no difference between the two distributions (90-10 vs. 66-33) in reading rate for Experiment 2. The difference between Experiment 1 & 2 is that in the former, the dialectal structure occurred at a higher proportion in the 80-20 distribution compared to the 40-60 distribution. In Experiment 2, the dialectal structure was the majority in both the 90-10 and 66-33 distributions. There was only a difference of 8 modifiers between the two distributions, in contrast to Experiment 1 where there was a difference of 25 modifiers between the 80-20 and 40-60 distributions.

There are two possible explanations for the lack of distribution effect over the course of Experiment 2. The first is that the self-paced reading task may be sensitive enough to find differences between high vs. low proportion of dialectal sentences (80% vs. 40%), but may not be sensitive enough to detect differences between proportions that are closer together (90% vs. 66%). Previous research has shown that effects from self-paced reading tasks are not as robust compared to other online reading paradigms (Boyce, Futrell, & Levy, 2020; Witzel, Witzel, & Forster, 2012). For example, methods such as eye-tracking were able show a garden-path effect for relative clauses with a high attachment site (e.g. *The son of the actress who introduced himself*) at the point of disambiguation, while the same effect was only obtained for self-paced reading when averaging all the reading times following disambiguation (Witzel et al., 2012). A more recent word-by-word reading paradigm known as the maze task allows words to be read one at a time, but participants are forced to choose between paired alternative words, only one of which correctly continues the sentence. The strength of the garden-path effects from the maze task was greater in magnitude compared to the effects from self-paced reading (Boyce et al.,

2020), and greater even compared to eye-tracking (Witzel et al., 2012). However, it is important to note that the maze task may require more of a processing load, and may not be tapping into the same processes as eyetracking or self-paced reading. Therefore, although Experiment 1 was able to find an effect at the disambiguating word without averaging together reading times over several words, it is possible that a more sensitive measure might be needed to find a similar effect for Experiment 2.

The second explanation for the results of Experiment 2 is that participants were only sensitive to which structure was the most frequent relative to the competing structure, but not the exact probability that it was occurring at within the linguistic environment. This explanation is consistent with the findings from Experiment 1, as the dialectal structure was the more frequent structure relative to the modifier structure in the 80-20 distribution, but not in the 40-60 distribution. If this is the case, then this raises questions about experience-based models that imply people can keep track of specific probabilities. Probabilistic models (e.g. Hale, 2001; Jurafsky, 1996; Levy, 2008) put more emphasis on probability theory compared to constraint-based approaches (e.g. MacDonald et al., 1994), in which probabilities are computed based on the input received from the comprehender. For example, Jurafsky (1996) proposed that interpretations are ranked in terms of probability, and low-ranked structures are pruned due to limitations in memory and attention (Narayanan & Jurafsky, 2002). Likewise, Hale (2001) proposed that all possible structures are maintained, and probabilities are computed based on the frequency of the structure occurring within a probabilistic grammar.

These models suggest that the probabilities of different syntactic structures are stored in memory, and that a structure occurring 90% of the time should be ranked higher and read faster than the one occurring 66% of the time. The findings from Experiment 1 & 2 imply that

comprehenders can at most keep track of the structure that is the frequent alternative. However, this does not fully rule out probability-based models, as it is possible that the theory behind these models still hold but on a less fine-grained level. Furthermore, the current study uses only two competing syntactic structures, the dialectal and modifier structure. It is entirely possible that results may differ depending on the number of competing structures within the linguistic environment.

The results from Experiment 3 are interesting because participants read the dialectal *wants* sentences faster after being trained on the dialectal *needs* sentences than the participants who were trained on the dialectal *wants* sentences. Though this replicates the finding from Kaschak & Glenberg (2004), there was no baseline condition where participants received the standard *needs* sentences before being tested on the dialectal structure. Therefore, I cautiously conclude that generalization did occur across the two verbs for the dialectal structure, with the caveat that this needs to be further backed up with a baseline condition.

Since there was no effect of distribution in either of the two training conditions, this limits the type of statistical information that can generalize. The caveat is that there also was no effect of distribution for the dialectal *wants* sentences, over the course of the exposure phase. Therefore, it is hard to make any clear conclusions about this data without following up with another experiment with better controls. However, the presence of the modifier *wants* sentences did seem to play a role, as shown by the difference between the two training conditions. This implies that the competition between the modifier and dialectal structure in the *wants* training condition was enough to slow down reading of the dialectal *wants* sentences in the test phase, compared to the dialectal *needs* training condition.

One possibility for why there was a difference in training condition is that the relative frequency of competing structures does matter. Reading times for the test sentence were faster for the *needs* training condition because the relative frequency of the modifier *needs* structure did not generalize over to the modifier *wants* structure. This may be because participants in the *needs* training condition never read modifier sentences that competed with the test sentences. In contrast, this was not true for the *wants* training condition. The modifier *wants* sentences were competing with the dialectal *wants* sentences in the test phase, but only in the *wants* training condition. On this view, the relative frequency of the dialectal and modifier structure did not generalize across verbs because there was no competitive structure within the linguistic input. However, if all participants read some number of modifier *wants* sentences during the exposure phase, the difference between the training conditions may disappear.

The above explanation would be in line with fine-grained lexicalist-based models, as information about relative frequency is tied to individual verbs and their alternative co-occurring syntactic structures. However, since the test sentences were read faster in the *needs* training condition, this is also consistent with models that suggest people are sensitive to more verb-general statistics. Although the latter needs to be followed up, generalization from *needs* to *wants* was also found in Kaschak & Glenberg (2004). Therefore, it would not be surprising if those results replicated in a better controlled study.

Lastly, there is also the possibility that participants may be adapting to any ungrammatical structure during the test phase, and not just the test sentences that use the dialectal structure. With that said, both Experiment 1 & 2 show differences between the dialectal and standard *needs* sentences; participants adapt at a faster rate to the dialectal sentences, and reading times look similar across the two sentence types by the end of the experiment (see also

Kaschak & Glenberg, 2004). Furthermore, priming of ungrammatical structures has led to a priming effect on the grammatical counterpart (Ivanova et al., 2012). This suggests that underlying syntactic structure needs to be consistent across the prime and target structure in order to lead to facilitation.

Evaluation of possible theoretical frameworks

The main finding from the current study is that relative frequency matters for syntactic processing, as shown in Experiment 1. Critically, this rules out theoretical models where only raw frequency accounts for processing difficulty. This is consistent with experience-based models where relative frequency plays a role in processing, such as in constraint-based models (e.g. MacDonald et al., 1994) and probabilistic models (e.g. Jurafsky 1996).

However, there still remain open questions about the level of detail that comprehenders can acquire from the linguistic environment. Experiment 2 failed to find evidence for comprehenders keeping track of fine-grained estimates of relative frequency. This suggests that perhaps comprehenders can only obtain rough estimates of frequency information, although further work is needed before coming to this conclusion. Therefore, this question has not been fully addressed.

In addition, it is unclear what kind of syntactic information is generalized. Experiment 3 failed to find generalization of distributional information from *needs* to *wants*. Therefore, we cannot rule out any account that proposes generalization within its framework, or an account that does not allow generalization. The findings from Experiment 3 raise the possibility that the underlying dialectal structure may be generalized, but as with the previous experiment, further work is needed before coming to this conclusion.

In regards to the mechanisms proposed to underlie syntactic priming, the current study does not directly test between an implicit learning account and a residual activation account. The main difference between these two accounts is that the former predicts long-term persistence of priming, while the latter predicts short-lived effects of priming. The current study does not test whether priming persists after exposure. Participants are continuously exposed to the dialectal sentences over the course of a single session, and are not tested on this structure in another session after a delay. Since the manipulation in relative frequency affected adaptation rate, this could be evidence for an implicit learning account, since residual activation accounts do not specify the role of distributional information. This would need to be explored further, as the primary purpose of this study was not to directly test between these two mechanisms.

Lastly, connectionist models from the field of language learning form the basis of current theoretical models of syntactic processing (e.g. Bates & MacWhinney, 1987; MacDonald et al., 1994). Since relative frequency was found to affect syntactic processing, it may also affect how children make inferences about subcategorization. Previous work has shown that learners can use relative frequency to make inferences about when to generalize (Wonnacott et al., 2008) or lead to regularization of inconsistent grammatical forms (Hudson Kam & Newport, 2005; 2009). Future work should explore how different syntactic distributions affect learning of subcategorization frames, and whether varying the relative frequencies of competing structures can help or hinder this learning. Ultimately, investigating this may help inform what kinds of linguistic environments work best for learning syntax.

Conclusions and future work

The current project tests whether comprehenders are sensitive to syntactic distributional information, which is an assumption made by theoretical models and recent research on syntactic

adaptation. This set of studies show that although relative frequency does matter for syntactic processing, there are still some open questions in regards to the level of statistical detail comprehenders are sensitive to, and what kind of information can be generalized. The current study uses the dialectal structure to test these questions, but it remains unclear whether the current findings can be replicated in familiar structures, such as reduced relative clauses. Replicating the finding from Experiment 1 in a different structure would provide additional support for the role of distributional information in processing.

One aspect that has not been addressed within the current study, is the relationship between relative frequency and raw frequency. Currently, the interaction between relative and raw frequency is not fully specified in experience-based models. Though there is an emphasis on distributional information, it is not clear how it interacts with raw frequency. For one, syntactic adaptation studies only manipulate the raw frequency, which also leads to an increased in relative frequency (Fine et al., 2013). In addition, it is hard to separate out the effects of relative frequency from raw frequency in correlational studies. Though the current study suggests an effect of relative frequency independent of overall exposure, this effect may not be as large in magnitude compared to raw frequency alone. If this is the case, then a potential follow-up to Experiment 1 could test this by manipulating the raw frequency while holding the relative frequency constant. Testing this would then allow for comparisons between the effect of relative frequency from Experiment 1, and the effect of raw frequency. If an increase in raw frequency leads to more facilitation that the effect of relative frequency, then experience-based models need to specify that relationship more clearly.

In conclusion, this is the first study to find that syntactic processing is affected by changes to relative frequency, independent of raw frequency. This is critical because previous

work on syntactic adaptation assume that comprehenders develop an implicit knowledge of the distribution of syntactic structures to help facilitate processing. Furthermore, work that does investigate the role of relative frequency is limited to correlational work between ease of processing and frequency statistics from corpora. Future work can focus on the relationship between raw and relative frequency, in addition to further exploring the unresolved issues from the current study.

APPENDIX A: STIMULI FROM EXPERIMENT 1

List 1: 80-20 Distribution, Ambiguous

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The parents completely disagreed with the new regulations.
The unpopular anthropology professor was finally going to retire.
The fire needs stoked to keep it from burning out.
The roofer got a terrible sunburn from being outside all day.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The package arrived too late to be of any use.
The large pumpkin needs carved before it can be put on display.
The girls on the basketball team tried to practice all summer.
The meal needs cooked vegetables so the guests will be happy.
The cyclist wanted to train throughout the winter so he moved to Hawaii.
The lock needs checked so we can be sure the apartment is secure.
The new student disappeared after only three days of school.
The new experiment was the source of a great deal of excitement in the lab.
The wedding had to be rescheduled because of a hurricane.
The computer program needs debugged before it can be handed in.
The children in the park could be heard three blocks away.
The pilots flew over the city where they had just had a wonderful weekend.
The television needs repaired before the series premiere airs.
The runners were in much better shape in the fall than in the winter.
All the undergraduates in the class had trouble keeping up.
The laptop needs connected wires to function properly.
The textbooks were too expensive for most of the students.
The shirt needs ironed so the actor can wear it tonight.
The lawnmower did not always function properly when the grass was wet.
The term papers from the previous semester were beginning to accumulate on the teacher’s desk.
The green light bulb needs changed since it just burned out.
The teachers had to move their classes online due to a pandemic.
All the guitarists learned to play when they were teenagers.
The blank CD needs burned so it can be given to the DJ.
The candles on the birthday cake were blown out in seconds.
The apple pie needs baked walnuts sprinkled on top of its crust.
The real estate agent blundered when he revealed the house's plumbing problems.
The indoor plants dried out due to lack of proper watering.
The piano needs tuned so the musicians can play.
The leader of the gambling ring was always mistrustful of his bodyguards.
Each of the divers had a strict regimen so that they would be prepared for the swim meet.
The phone needs charged since its battery does not last long.
The school principal had to work constantly all summer dealing with paperwork.
The library was open to all members of the community since it was supported by tax dollars.
The students went on a trip to Paris one summer to improve their language skills.

The laundry needs rinsed before it can be put in the dryer.
The street lamps usually came on automatically just before dark.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The term paper needs revised before the due date tomorrow.
The sunburned boys who were fed the hot dogs got a stomach ache.
The legal file needs completed documents before it can be closed.
The university's math courses were among the nation's most rigorous.
The room needs lighted so the students can read their books.
The people downtown are frustrated by the lack of available parking.
The company's health plan did not cover even the most basic health services.
The patio needs renovated for the birthday party.
The landscaper boasted of his achievements constantly.
The physics professor at the university was finally going to retire.
The basketball game ended with the home team missing the winning shot.
The wood floor needs cleaned before the student's parents get here.
The university students sometimes move into the dormitories as early as August.
Many of the soldiers were looking forward to going home for the winter holidays.
The old chair needs fixed so the guests can sit on it.
The angry customers decided to leave the restaurant.
Each of the cab drivers had their own favorite route to get to the airport.
The power plant deserved more attention from the candidates during the election.
The white walls need painted to keep the tenants happy.
The eccentric professor always inspired his students to think critically about their work.
The red wine needs refrigerated cheese to complement it.
The quilts were sold by the side of the road for ten dollars.
The car salesman waited anxiously for more customers.
The film needs copyrighted before it can be released.
The valuable lamp was broken by the mischievous boy.
The spy was unable to cross the field without being seen.
The engineers at the plant had to wear helmets when they went near the machines.
The oranges need peeled before they can be eaten.
The priceless ceramic sculpture had to sit on the top shelf of the lawyer's office.
The dance troupe came to set up their equipment.
The wealthy bankers liked to frequent the bars downtown.
The potatoes need boiled before they can be used in the soup.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

List 2: 40-60 Distribution, Ambiguous

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The shack needs refurbished wood for its renovations.
The unpopular anthropology professor was finally going to retire.
The fire needs stoked to keep it from burning out.
The ceramic tile needs washed stickers to be put on it.
The shoppers love to spend all day at the mall on the weekends.

The coffee shop was a popular hangout for political activists.
The program needs downloaded files before it can run.
The large pumpkin needs carved before it can be put on display.
The girls on the basketball team tried to practice all summer.
The meal needs cooked vegetables so the guests will be happy.
The cyclist wanted to train throughout the winter so he moved to Hawaii.
The lock needs checked so we can be sure the apartment is secure.
The sales report needs updated information before the end of the quarter.
The new experiment was the source of a great deal of excitement in the lab.
The noodles need heated sauce to complete the meal.
The computer program needs debugged before it can be handed in.
The curtain needs torn patches to be ironed on for the show.
The pilots flew over the city where they had just had a wonderful weekend.
The television needs repaired before the series premiere airs.
The runners were in much better shape in the fall than in the winter.
The beautiful picture needs trimmed paper to hold it in the frame.
The laptop needs connected wires to function properly.
The textbooks were too expensive for most of the students.
The shirt needs ironed so the actor can wear it tonight.
The draft needs approved signatures for it to pass the committee.
The term papers from the previous semester were beginning to accumulate on the teacher’s desk.
The green light bulb needs changed since it just burned out.
The teachers had to move their classes online due to a pandemic.
The museum needs restored paintings since many were destroyed in the fire.
The blank CD needs burned so it can be given to the DJ.
The candles on the birthday cake were blown out in seconds.
The apple pie needs baked walnuts sprinkled on top of its crust.
The real estate agent blundered when he revealed the house's plumbing problems.
The display case needs polished trophies so the students can admire them.
The piano needs tuned so the musicians can play.
The leader of the gambling ring was always mistrustful of his bodyguards.
The new screws need tightened bolts to keep them in place.
The phone needs charged since its battery does not last long.
The zucchini needs chopped herbs for seasoning.
The library was open to all members of the community since it was supported by tax dollars.
The back lawn needs cut flowers to be sprinkled on it.
The laundry needs rinsed before it can be put in the dryer.
The workbench needs improved tools before it can be used again.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The term paper needs revised before the due date tomorrow.
The sunburned boys who were fed the hot dogs got a stomach ache.
The legal file needs completed documents before it can be closed.
The university's math courses were among the nation's most rigorous.
The room needs lighted so the students can read their books.
The people downtown are frustrated by the lack of available parking.
The oak cabinet needs dusted frames to be placed on its shelf.

The patio needs renovated for the birthday party.
The store entrance needs decorated signs to be placed in the windows.
The physics professor at the university was finally going to retire.
The literary magazine needs edited poems before it can be printed.
The wood floor needs cleaned before the student's parents get here.
The university students sometimes move into the dormitories as early as August.
The pizza needs sliced pepperonis to be put on top.
The old chair needs fixed so the guests can sit on it.
The angry customers decided to leave the restaurant.
The plastic bench needs folded paper to cover it.
The photocopier needs recycled paper to comply with our environmental policy.
The white walls need painted to keep the tenants happy.
The eccentric professor always inspired his students to think critically about their work.
The red wine needs refrigerated cheese to complement it.
The quilts were sold by the side of the road for ten dollars.
The pork chops need glazed pineapples to be cooked with them.
The film needs copyrighted before it can be released.
The valuable lamp was broken by the mischievous boy.
The table needs disinfected placemats before dinner can be eaten.
The science book needs modified chapters before it can be published.
The oranges need peeled before they can be eaten.
The couch needs measured fabric for upholstery.
The dance troupe came to set up their equipment.
The car needs washed hubcaps so it will look totally clean.
The potatoes need boiled before they can be used in the soup.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

List 3: 80-20 Distribution, Unambiguous

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The parents completely disagreed with the new regulations.
The unpopular anthropology professor was finally going to retire.
The fire needs to be stoked to keep it from burning out.
The roofer got a terrible sunburn from being outside all day.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The package arrived too late to be of any use.
The large pumpkin needs to be carved before it can be put on display.
The girls on the basketball team tried to practice all summer.
The meal needs cooked vegetables so the guests will be happy.
The cyclist wanted to train throughout the winter so he moved to Hawaii.
The lock needs to be checked so we can be sure the apartment is secure.
The new student disappeared after only three days of school.
The new experiment was the source of a great deal of excitement in the lab.

The wedding had to be rescheduled because of a hurricane.
The computer program needs to be debugged before it can be handed in.
The children in the park could be heard three blocks away.
The pilots flew over the city where they had just had a wonderful weekend.
The television needs to be repaired before the series premiere airs.
The runners were in much better shape in the fall than in the winter.
All the undergraduates in the class had trouble keeping up.
The laptop needs connected wires to function properly.
The textbooks were too expensive for most of the students.
The shirt needs to be ironed so the actor can wear it tonight.
The lawnmower did not always function properly when the grass was wet.
The term papers from the previous semester were beginning to accumulate on the teacher’s desk.
The green light bulb needs to be changed since it just burned out.
The teachers had to move their classes online due to a pandemic.
All the guitarists learned to play when they were teenagers.
The blank CD needs to be burned so it can be given to the DJ.
The candles on the birthday cake were blown out in seconds.
The apple pie needs baked walnuts sprinkled on top of its crust.
The real estate agent blundered when he revealed the house's plumbing problems.
The indoor plants dried out due to lack of proper watering.
The piano needs to be tuned so the musicians can play.
The leader of the gambling ring was always mistrustful of his bodyguards.
Each of the divers had a strict regimen so that they would be prepared for the swim meet.
The phone needs to be charged since its battery does not last long.
The school principal had to work constantly all summer dealing with paperwork.
The library was open to all members of the community since it was supported by tax dollars.
The students went on a trip to Paris one summer to improve their language skills.
The laundry needs to be rinsed before it can be put in the dryer.
The street lamps usually came on automatically just before dark.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The term paper needs to be revised before the due date tomorrow.
The sunburned boys who were fed the hot dogs got a stomach ache.
The legal file needs completed documents before it can be closed.
The university's math courses were among the nation's most rigorous.
The room needs to be lighted so the students can read their books.
The people downtown are frustrated by the lack of available parking.
The company's health plan did not cover even the most basic health services.
The patio needs to be renovated for the birthday party.
The landscaper boasted of his achievements constantly.
The physics professor at the university was finally going to retire.
The basketball game ended with the home team missing the winning shot.
The wood floor needs to be cleaned before the student's parents get here.
The university students sometimes move into the dormitories as early as August.
Many of the soldiers were looking forward to going home for the winter holidays.
The old chair needs to be fixed so the guests can sit on it.
The angry customers decided to leave the restaurant.

Each of the cab drivers had their own favorite route to get to the airport.
The power plant deserved more attention from the candidates during the election.
The white walls need to be painted to keep the tenants happy.
The eccentric professor always inspired his students to think critically about their work.
The red wine needs refrigerated cheese to complement it.
The quilts were sold by the side of the road for ten dollars.
The car salesman waited anxiously for more customers.
The film needs to be copyrighted before it can be released.
The valuable lamp was broken by the mischievous boy.
The spy was unable to cross the field without being seen.
The engineers at the plant had to wear helmets when they went near the machines.
The oranges need to be peeled before they can be eaten.
The priceless ceramic sculpture had to sit on the top shelf of the lawyer's office.
The dance troupe came to set up their equipment.
The wealthy bankers liked to frequent the bars downtown.
The potatoes need to be boiled before they can be used in the soup.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

List 4: 40-60 Distribution, Unambiguous

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The shack needs refurbished wood for its renovations.
The unpopular anthropology professor was finally going to retire.
The fire needs to be stoked to keep it from burning out.
The ceramic tile needs washed stickers to be put on it.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The program needs downloaded files before it can run.
The large pumpkin needs to be carved before it can be put on display.
The girls on the basketball team tried to practice all summer.
The meal needs cooked vegetables so the guests will be happy.
The cyclist wanted to train throughout the winter so he moved to Hawaii.
The lock needs to be checked so we can be sure the apartment is secure.
The sales report needs updated information before the end of the quarter.
The new experiment was the source of a great deal of excitement in the lab.
The noodles need heated sauce to complete the meal.
The computer program needs to be debugged before it can be handed in.
The curtain needs torn patches to be ironed on for the show.
The pilots flew over the city where they had just had a wonderful weekend.
The television needs to be repaired before the series premiere airs.
The runners were in much better shape in the fall than in the winter.
The beautiful picture needs trimmed paper to hold it in the frame.
The laptop needs connected wires to function properly.
The textbooks were too expensive for most of the students.

The shirt needs to be ironed so the actor can wear it tonight.
The draft needs approved signatures for it to pass the committee.
The term papers from the previous semester were beginning to accumulate on the teacher’s desk.
The green light bulb needs to be changed since it just burned out.
The teachers had to move their classes online due to a pandemic.
The museum needs restored paintings since many were destroyed in the fire.
The blank CD needs to be burned so it can be given to the DJ.
The candles on the birthday cake were blown out in seconds.
The apple pie needs baked walnuts sprinkled on top of its crust.
The real estate agent blundered when he revealed the house's plumbing problems.
The display case needs polished trophies so the students can admire them.
The piano needs to be tuned so the musicians can play.
The leader of the gambling ring was always mistrustful of his bodyguards.
The new screws need tightened bolts to keep them in place.
The phone needs to be charged since its battery does not last long.
The zucchini needs chopped herbs for seasoning.
The library was open to all members of the community since it was supported by tax dollars.
The back lawn needs cut flowers to be sprinkled on it.
The laundry needs to be rinsed before it can be put in the dryer.
The workbench needs improved tools before it can be used again.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The term paper needs to be revised before the due date tomorrow.
The sunburned boys who were fed the hot dogs got a stomach ache.
The legal file needs completed documents before it can be closed.
The university's math courses were among the nation's most rigorous.
The room needs to be lighted so the students can read their books.
The people downtown are frustrated by the lack of available parking.
The oak cabinet needs dusted frames to be placed on its shelf.
The patio needs to be renovated for the birthday party.
The store entrance needs decorated signs to be placed in the windows.
The physics professor at the university was finally going to retire.
The literary magazine needs edited poems before it can be printed.
The wood floor needs to be cleaned before the student's parents get here.
The university students sometimes move into the dormitories as early as August.
The pizza needs sliced pepperonis to be put on top.
The old chair needs to be fixed so the guests can sit on it.
The angry customers decided to leave the restaurant.
The plastic bench needs folded paper to cover it.
The photocopier needs recycled paper to comply with our environmental policy.
The white walls need to be painted to keep the tenants happy.
The eccentric professor always inspired his students to think critically about their work.
The red wine needs refrigerated cheese to complement it.
The quilts were sold by the side of the road for ten dollars.
The pork chops need glazed pineapples to be cooked with them.
The film needs to be copyrighted before it can be released.
The valuable lamp was broken by the mischievous boy.

The table needs disinfected placemats before dinner can be eaten.
The science book needs modified chapters before it can be published.
The oranges need to be peeled before they can be eaten.
The couch needs measured fabric for upholstery.
The dance troupe came to set up their equipment.
The car needs washed hubcaps so it will look totally clean.
The potatoes need to be boiled before they can be used in the soup.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

APPENDIX B: STIMULI FROM EXPERIMENT 2

List 1: 90-10 Distribution, Ambiguous

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The parents completely disagreed with the new regulations.
The unpopular anthropology professor was finally going to retire.
The fire needs stoked to keep it from burning out.
The roofer got a terrible sunburn from being outside all day.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The package arrived too late to be of any use.
The large pumpkin needs carved before it can be put on display.
The girls on the basketball team tried to practice all summer.
The new experiment was the source of a great deal of excitement in the lab.
The cyclist wanted to train throughout the winter so he moved to Hawaii.
The lock needs checked so we can be sure the apartment is secure.
The new student disappeared after only three days of school.
The meal needs cooked vegetables so the guests will be happy.
The wedding had to be rescheduled because of a hurricane.
The computer program needs debugged before it can be handed in.
The children in the park could be heard three blocks away.
The pilots flew over the city where they had just had a wonderful weekend.
The television needs repaired before the series premiere airs.
The runners were in much better shape in the fall than in the winter.
All the undergraduates in the class had trouble keeping up.
The grocery store ran out of cleaning supplies and hand sanitizer.
The textbooks were too expensive for most of the students.
The shirt needs ironed so the actor can wear it tonight.
The lawnmower did not always function properly when the grass was wet.
The term papers from the previous semester were beginning to accumulate on the teacher’s desk.
The green light bulb needs changed since it just burned out.
The teachers had to move their classes online due to a pandemic.
All the guitarists learned to play when they were teenagers.
The blank CD needs burned so it can be given to the DJ.
The candles on the birthday cake were blown out in seconds.
The ice skater was skilled enough to qualify for the U.S. olympic team.
The real estate agent blundered when he revealed the house's plumbing problems.
The indoor plants dried out due to lack of proper watering.
The piano needs tuned so the musicians can play.
The leader of the gambling ring was always mistrustful of his bodyguards.
Each of the divers had a strict regimen so that they would be prepared for the swim meet.
The phone needs charged since its battery does not last long.
The school principal had to work constantly all summer dealing with paperwork.
The library was open to all members of the community since it was supported by tax dollars.
The students went on a trip to Paris one summer to improve their language skills.

The laundry needs rinsed before it can be put in the dryer.
The street lamps usually came on automatically just before dark.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The term paper needs revised before the due date tomorrow.
The sunburned boys who were fed the hot dogs got a stomach ache.
The legal file needs completed documents before it can be closed.
The university's math courses were among the nation's most rigorous.
The room needs lighted so the students can read their books.
The people downtown are frustrated by the lack of available parking.
The company's health plan did not cover even the most basic health services.
The patio needs renovated for the birthday party.
The landscaper boasted of his achievements constantly.
The physics professor at the university was finally going to retire.
The basketball game ended with the home team missing the winning shot.
The wood floor needs cleaned before the student's parents get here.
The university students sometimes move into the dormitories as early as August.
Many of the soldiers were looking forward to going home for the winter holidays.
The old chair needs fixed so the guests can sit on it.
The angry customers decided to leave the restaurant.
Each of the cab drivers had their own favorite route to get to the airport.
The power plant deserved more attention from the candidates during the election.
The white walls need painted to keep the tenants happy.
The eccentric professor always inspired his students to think critically about their work.
The chemistry professor was disappointed by the grades on the last exam.
The quilts were sold by the side of the road for ten dollars.
The car salesman waited anxiously for more customers.
The film needs copyrighted before it can be released.
The valuable lamp was broken by the mischievous boy.
The spy was unable to cross the field without being seen.
The engineers at the plant had to wear helmets when they went near the machines.
The oranges need peeled before they can be eaten.
The priceless ceramic sculpture had to sit on the top shelf of the lawyer's office.
The dance troupe came to set up their equipment.
The wealthy bankers liked to frequent the bars downtown.
The potatoes need boiled before they can be used in the soup.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

List 2: 66-33 Distribution, Ambiguous

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The parents completely disagreed with the new regulations.
The unpopular anthropology professor was finally going to retire.
The fire needs stoked to keep it from burning out.
The roofer got a terrible sunburn from being outside all day.

The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The program needs downloaded files before it can run.
The large pumpkin needs carved before it can be put on display.
The girls on the basketball team tried to practice all summer.
The photocopier needs recycled paper to comply with our environmental policy.
The cyclist wanted to train throughout the winter so he moved to Hawaii.
The lock needs checked so we can be sure the apartment is secure.
The new student disappeared after only three days of school.
The dolphins at the aquarium performed many tricks during the show.
The wedding had to be rescheduled because of a hurricane.
The computer program needs debugged before it can be handed in.
The curtain needs torn patches to be ironed on for the show.
The pilots flew over the city where they had just had a wonderful weekend.
The television needs repaired before the series premiere airs.
The runners were in much better shape in the fall than in the winter.
All the undergraduates in the class had trouble keeping up.
The laptop needs connected wires to function properly.
The textbooks were too expensive for most of the students.
The shirt needs ironed so the actor can wear it tonight.
The lawnmower did not always function properly when the grass was wet.
The term papers from the previous semester were beginning to accumulate on the teacher's desk.
The green light bulb needs changed since it just burned out.
The teachers had to move their classes online due to a pandemic.
All the guitarists learned to play when they were teenagers.
The blank CD needs burned so it can be given to the DJ.
The candles on the birthday cake were blown out in seconds.
The apple pie needs baked walnuts sprinkled on top of its crust.
The real estate agent blundered when he revealed the house's plumbing problems.
The indoor plants dried out due to lack of proper watering.
The piano needs tuned so the musicians can play.
The leader of the gambling ring was always mistrustful of his bodyguards.
Each of the divers had a strict regimen so that they would be prepared for the swim meet.
The phone needs charged since its battery does not last long.
The school principal had to work constantly all summer dealing with paperwork.
The library was open to all members of the community since it was supported by tax dollars.
The back lawn needs cut flowers to be sprinkled on it.
The laundry needs rinsed before it can be put in the dryer.
The street lamps usually came on automatically just before dark.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The term paper needs revised before the due date tomorrow.
The sunburned boys who were fed the hot dogs got a stomach ache.
The legal file needs completed documents before it can be closed.
The university's math courses were among the nation's most rigorous.
The room needs lighted so the students can read their books.
The people downtown are frustrated by the lack of available parking.

The company's health plan did not cover even the most basic health services.
The patio needs renovated for the birthday party.
The landscaper boasted of his achievements constantly.
The physics professor at the university was finally going to retire.
The basketball game ended with the home team missing the winning shot.
The wood floor needs cleaned before the student's parents get here.
The university students sometimes move into the dormitories as early as August.
The pizza needs sliced pepperonis to be put on top.
The old chair needs fixed so the guests can sit on it.
The angry customers decided to leave the restaurant.
Each of the cab drivers had their own favorite route to get to the airport.
The power plant deserved more attention from the candidates during the election.
The white walls need painted to keep the tenants happy.
The eccentric professor always inspired his students to think critically about their work.
The chemistry professor was disappointed by the grades on the last exam.
The quilts were sold by the side of the road for ten dollars.
The pork chops need glazed pineapples to be cooked with them.
The film needs copyrighted before it can be released.
The valuable lamp was broken by the mischievous boy.
The spy was unable to cross the field without being seen.
The engineers at the plant had to wear helmets when they went near the machines.
The oranges need peeled before they can be eaten.
The priceless ceramic sculpture had to sit on the top shelf of the lawyer's office.
The dance troupe came to set up their equipment.
The car needs washed hubcaps so it will look totally clean.
The potatoes need boiled before they can be used in the soup.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

List 3: 90-10 Distribution, Unambiguous

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The parents completely disagreed with the new regulations.
The unpopular anthropology professor was finally going to retire.
The fire needs to be stoked to keep it from burning out.
The roofer got a terrible sunburn from being outside all day.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The package arrived too late to be of any use.
The large pumpkin needs to be carved before it can be put on display.
The girls on the basketball team tried to practice all summer.
The new experiment was the source of a great deal of excitement in the lab.
The cyclist wanted to train throughout the winter so he moved to Hawaii.
The lock needs to be checked so we can be sure the apartment is secure.
The new student disappeared after only three days of school.

The meal needs cooked vegetables so the guests will be happy.
The wedding had to be rescheduled because of a hurricane.
The computer program needs to be debugged before it can be handed in.
The children in the park could be heard three blocks away.
The pilots flew over the city where they had just had a wonderful weekend.
The television needs to be repaired before the series premiere airs.
The runners were in much better shape in the fall than in the winter.
All the undergraduates in the class had trouble keeping up.
The grocery store ran out of cleaning supplies and hand sanitizer.
The textbooks were too expensive for most of the students.
The shirt needs to be ironed so the actor can wear it tonight.
The lawnmower did not always function properly when the grass was wet.
The term papers from the previous semester were beginning to accumulate on the teacher's desk.
The green light bulb needs to be changed since it just burned out.
The teachers had to move their classes online due to a pandemic.
All the guitarists learned to play when they were teenagers.
The blank CD needs to be burned so it can be given to the DJ.
The candles on the birthday cake were blown out in seconds.
The ice skater was skilled enough to qualify for the U.S. olympic team.
The real estate agent blundered when he revealed the house's plumbing problems.
The indoor plants dried out due to lack of proper watering.
The piano needs to be tuned so the musicians can play.
The leader of the gambling ring was always mistrustful of his bodyguards.
Each of the divers had a strict regimen so that they would be prepared for the swim meet.
The phone needs to be charged since its battery does not last long.
The school principal had to work constantly all summer dealing with paperwork.
The library was open to all members of the community since it was supported by tax dollars.
The students went on a trip to Paris one summer to improve their language skills.
The laundry needs to be rinsed before it can be put in the dryer.
The street lamps usually came on automatically just before dark.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The term paper needs to be revised before the due date tomorrow.
The sunburned boys who were fed the hot dogs got a stomach ache.
The legal file needs completed documents before it can be closed.
The university's math courses were among the nation's most rigorous.
The room needs to be lighted so the students can read their books.
The people downtown are frustrated by the lack of available parking.
The company's health plan did not cover even the most basic health services.
The patio needs to be renovated for the birthday party.
The landscaper boasted of his achievements constantly.
The physics professor at the university was finally going to retire.
The basketball game ended with the home team missing the winning shot.
The wood floor needs to be cleaned before the student's parents get here.
The university students sometimes move into the dormitories as early as August.
Many of the soldiers were looking forward to going home for the winter holidays.
The old chair needs to be fixed so the guests can sit on it.

The angry customers decided to leave the restaurant.
Each of the cab drivers had their own favorite route to get to the airport.
The power plant deserved more attention from the candidates during the election.
The white walls need to be painted to keep the tenants happy.
The eccentric professor always inspired his students to think critically about their work.
The chemistry professor was disappointed by the grades on the last exam.
The quilts were sold by the side of the road for ten dollars.
The car salesman waited anxiously for more customers.
The film needs to be copyrighted before it can be released.
The valuable lamp was broken by the mischievous boy.
The spy was unable to cross the field without being seen.
The engineers at the plant had to wear helmets when they went near the machines.
The oranges need to be peeled before they can be eaten.
The priceless ceramic sculpture had to sit on the top shelf of the lawyer's office.
The dance troupe came to set up their equipment.
The wealthy bankers liked to frequent the bars downtown.
The potatoes need to be boiled before they can be used in the soup.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

List 4: 66-33 Distribution, Unambiguous

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The parents completely disagreed with the new regulations.
The unpopular anthropology professor was finally going to retire.
The fire needs to be stoked to keep it from burning out.
The roofer got a terrible sunburn from being outside all day.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The program needs downloaded files before it can run.
The large pumpkin needs to be carved before it can be put on display.
The girls on the basketball team tried to practice all summer.
The photocopier needs recycled paper to comply with our environmental policy.
The cyclist wanted to train throughout the winter so he moved to Hawaii.
The lock needs to be checked so we can be sure the apartment is secure.
The new student disappeared after only three days of school.
The dolphins at the aquarium performed many tricks during the show.
The wedding had to be rescheduled because of a hurricane.
The computer program needs to be debugged before it can be handed in.
The curtain needs torn patches to be ironed on for the show.
The pilots flew over the city where they had just had a wonderful weekend.
The television needs to be repaired before the series premiere airs.
The runners were in much better shape in the fall than in the winter.
All the undergraduates in the class had trouble keeping up.
The laptop needs connected wires to function properly.

The textbooks were too expensive for most of the students.
The shirt needs to be ironed so the actor can wear it tonight.
The lawnmower did not always function properly when the grass was wet.
The term papers from the previous semester were beginning to accumulate on the teacher’s desk.
The green light bulb needs to be changed since it just burned out.
The teachers had to move their classes online due to a pandemic.
All the guitarists learned to play when they were teenagers.
The blank CD needs to be burned so it can be given to the DJ.
The candles on the birthday cake were blown out in seconds.
The apple pie needs baked walnuts sprinkled on top of its crust.
The real estate agent blundered when he revealed the house's plumbing problems.
The indoor plants dried out due to lack of proper watering.
The piano needs to be tuned so the musicians can play.
The leader of the gambling ring was always mistrustful of his bodyguards.
Each of the divers had a strict regimen so that they would be prepared for the swim meet.
The phone needs to be charged since its battery does not last long.
The school principal had to work constantly all summer dealing with paperwork.
The library was open to all members of the community since it was supported by tax dollars.
The back lawn needs cut flowers to be sprinkled on it.
The laundry needs to be rinsed before it can be put in the dryer.
The street lamps usually came on automatically just before dark.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The term paper needs to be revised before the due date tomorrow.
The sunburned boys who were fed the hot dogs got a stomach ache.
The legal file needs completed documents before it can be closed.
The university's math courses were among the nation's most rigorous.
The room needs to be lighted so the students can read their books.
The people downtown are frustrated by the lack of available parking.
The company's health plan did not cover even the most basic health services.
The patio needs to be renovated for the birthday party.
The landscaper boasted of his achievements constantly.
The physics professor at the university was finally going to retire.
The basketball game ended with the home team missing the winning shot.
The wood floor needs to be cleaned before the student's parents get here.
The university students sometimes move into the dormitories as early as August.
The pizza needs sliced pepperonis to be put on top.
The old chair needs to be fixed so the guests can sit on it.
The angry customers decided to leave the restaurant.
Each of the cab drivers had their own favorite route to get to the airport.
The power plant deserved more attention from the candidates during the election.
The white walls need to be painted to keep the tenants happy.
The eccentric professor always inspired his students to think critically about their work.
The chemistry professor was disappointed by the grades on the last exam.
The quilts were sold by the side of the road for ten dollars.
The pork chops need glazed pineapples to be cooked with them.
The film needs to be copyrighted before it can be released.

The valuable lamp was broken by the mischievous boy.
The spy was unable to cross the field without being seen.
The engineers at the plant had to wear helmets when they went near the machines.
The oranges need to be peeled before they can be eaten.
The priceless ceramic sculpture had to sit on the top shelf of the lawyer's office.
The dance troupe came to set up their equipment.
The car needs washed hubcaps so it will look totally clean.
The potatoes need to be boiled before they can be used in the soup.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

APPENDIX C: STIMULI FROM EXPERIMENT 3

Test Phase:

The shaggy dog wants washed before it is time to go to bed.
The astronomer discovered a new planet a couple days ago.
The grocery store ran out of cleaning supplies and hand sanitizer.
The painter wants cleaned before heading to the birthday party.
The graduate student applied to many job positions but only got one offer.
The academics want trained on new methodology in their field.
The newly released movie did not receive a lot of praise from critics.
The radio station played new releases every day without any commercials.
The price of the streaming service increased despite complaints from customers.
The factory worker wants supervised while working on the new machine.
The ice skater was skilled enough to qualify for the U.S. olympic team.
The local animal shelter had all of their animals adopted over the weekend.
The surfers were surprised by the large waves at the beach.
The college professor wants organized before the semester starts in two weeks.
The chemistry professor was disappointed by the grades on the last exam.
The brilliant scientist wants photographed for the town newspaper.
All the athletes on the football team were excited about the upcoming championship.
The shack next to the highway caught on fire a few years ago.
The customer wants refunded since there was a lawsuit associated with the product.
The birds liked the new birdfeeder that was in the park.
The new restaurant finally opened to the public over the summer.
The company wants educated on issues relating to social justice.
The hikers brought water and trail mix with them on their trip.
The plumber fixed all the leaks under the kitchen sink.
The new book was on the bestseller list for eight weeks in a row.
The university wants supported by large donations from alumni.
The museum opened its new exhibit on whales at the beginning of the month.
The campers set up their tents near the lake.
The dolphins at the aquarium performed many tricks during the show.
The financial advisors want convinced before making a decision about investing.

List 1: 80-20 Distribution, *Needs* Training

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The parents completely disagreed with the new regulations.
The unpopular anthropology professor was finally going to retire.
The chef needs praised for her extraordinary recipe for chicken soup.
The roofer got a terrible sunburn from being outside all day.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The package arrived too late to be of any use.
The cardio instructor needs energized for the morning class.

The girls on the basketball team tried to practice all summer.
The salesman needs updated information before the end of the quarter.
The cyclist had to train throughout the winter so he moved to Hawaii.
The injured soccer player needs treated by the team doctor.
The new student disappeared after only three days of school.
The new experiment was the source of a great deal of excitement in the lab.
The wedding had to be rescheduled because of a hurricane.
The doctor needs rested before the surgery tomorrow.
The children in the park could be heard three blocks away.
The pilots flew over the city where they had just had a wonderful weekend.
The valiant hero needs recognized for his courageous actions.
The runners were in much better shape in the fall than in the winter.
All the undergraduates in the class had trouble keeping up.
The adventurer needs glorified songs of his achievements.
The textbooks were too expensive for most of the students.
The writer needs inspired so that they can create a masterpiece.
The lawnmower did not always function properly when the grass was wet.
The term papers from the previous semester were beginning to accumulate on the teacher's desk.
The research assistant needs rewarded for all their hard work.
The teachers had to move their classes online due to a pandemic.
All the guitarists learned to play when they were teenagers.
The teacher needs appreciated for putting together the school curriculum.
The candles on the birthday cake were blown out in seconds.
The nurse needs disinfected needles placed in their respective drawer.
The real estate agent blundered when he revealed the house's plumbing problems.
The indoor plants dried out due to lack of proper watering.
The brightly colored parrot needs fed because she has been hungry for days.
The leader of the gambling ring was always mistrustful of his bodyguards.
Each of the divers had a strict regimen so that they would be prepared for the swim meet.
The landlord needs reimbursed for the damages to the property.
The school principal had to work constantly all summer dealing with paperwork.
The library was open to all members of the community since it was supported by tax dollars.
The students went on a trip to Paris one summer to improve their language skills.
The businesswoman needs prepared for the presentation.
The street lamps usually came on automatically just before dark.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The workers need paid for completing construction.
The sunburned boys who were fed the hot dogs got a stomach ache.
The school board needs pleased parents so that they can get more funding from the town.
The university's math courses were among the nation's most rigorous.
The customer needs served before everyone else in the restaurant.
The people downtown are frustrated by the lack of available parking.
The company's health plan did not cover even the most basic health services.
The cute baby needs held because he is feeling uneasy.
The landscaper boasted of his achievements constantly.
The physics professor at the university was finally going to retire.

The basketball game ended with the home team missing the winning shot.
The prospective students need accepted to the graduate program.
The university students sometimes move into the dormitories as early as August.
Many of the soldiers were looking forward to going home for the winter holidays.
The sheep need sheared before summer arrives in two months.
The angry customers decided to leave the restaurant.
Each of the cab drivers had their own favorite route to get to the airport.
The power plant deserved more attention from the candidates during the election.
The mayor needs respected after calming down the crowds.
The eccentric professor always inspired his students to think critically about their work.
The official needs translated documents for the court case.
The quilts were sold by the side of the road for ten dollars.
The car salesman waited anxiously for more customers.
The general needs honored for his wartime heroics six years ago.
The valuable lamp was broken by the mischievous boy.
The spy was unable to cross the field without being seen.
The engineers at the plant had to wear helmets when they went near the machines.
The ballet dancer needs featured in the upcoming performance.
The priceless ceramic sculpture had to sit on the top shelf of the lawyer's office.
The dance troupe came to set up their equipment.
The wealthy bankers liked to frequent the bars downtown.
The high school student needs tutored before the big math exam.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

List 2: 40-60 Distribution, *Needs* Training

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The board directors need accomplished doctors to make up most of the hospital staff.
The unpopular anthropology professor was finally going to retire.
The chef needs praised for her extraordinary recipe for chicken soup.
The soccer coach needs motivated athletes for the team.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The director needs nominated actors to attend the exclusive party after the award ceremony.
The cardio instructor needs energized for the morning class.
The girls on the basketball team tried to practice all summer.
The salesman needs updated information before the end of the quarter.
The cyclist had to train throughout the winter so he moved to Hawaii.
The injured soccer player needs treated by the team doctor.
The university dean needs talented professors to head up the psychology undergraduate program.
The new experiment was the source of a great deal of excitement in the lab.
The principal needs empowered students to take action within the community.
The doctor needs rested before the surgery tomorrow.
The competitive swimmer needs dried towels for after swim practice.

The pilots flew over the city where they had just had a wonderful weekend.
The valiant hero needs recognized for his courageous actions.
The runners were in much better shape in the fall than in the winter.
The children need brushed hair before going to school.
The adventurer needs glorified songs of his achievements.
The textbooks were too expensive for most of the students.
The writer needs inspired so that they can create a masterpiece.
The diver needs certified lifeguards keeping watch over the beach.
The term papers from the previous semester were beginning to accumulate on the teacher's desk.
The research assistant needs rewarded for all their hard work.
The teachers had to move their classes online due to a pandemic.
The employer needs determined applicants for the vacant position.
The teacher needs appreciated for putting together the school curriculum.
The candles on the birthday cake were blown out in seconds.
The nurse needs disinfected needles placed in their respective drawer.
The real estate agent blundered when he revealed the house's plumbing problems.
The conductor needs skilled musicians playing in the orchestra.
The brightly colored parrot needs fed because she has been hungry for days.
The leader of the gambling ring was always mistrustful of his bodyguards.
The veterinarian needs behaved pets at their practice.
The landlord needs reimbursed for the damages to the property.
The kids need animated movies shown at the theater during their spring break.
The library was open to all members of the community since it was supported by tax dollars.
The kindergarten teacher needs excited kids to attend class online.
The businesswoman needs prepared for the presentation.
The actor needs rehearsed performances scheduled before the opening of the show.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The workers need paid for completing construction.
The sunburned boys who were fed the hot dogs got a stomach ache.
The school board needs pleased parents so that they can get more funding from the town.
The university's math courses were among the nation's most rigorous.
The customer needs served before everyone else in the restaurant.
The people downtown are frustrated by the lack of available parking.
The lawyer needs approved papers by tomorrow morning.
The cute baby needs held because he is feeling uneasy.
The temporary worker needs assigned hours before the holidays.
The physics professor at the university was finally going to retire.
The bride and groom need recorded video of their wedding.
The prospective students need accepted to the graduate program.
The university students sometimes move into the dormitories as early as August.
The high school student needs appointed study hours for the upcoming exam.
The sheep need sheared before summer arrives in two months.
The angry customers decided to leave the restaurant.
The hotel manager needs satisfied guests at each of their hotels.
The artist needs developed photographs before the gallery opens in two days.
The mayor needs respected after calming down the crowds.

The eccentric professor always inspired his students to think critically about their work.
The official needs translated documents for the court case.
The quilts were sold by the side of the road for ten dollars.
The young agent needs married couples to lease the nice apartment units.
The general needs honored for his wartime heroics six years ago.
The valuable lamp was broken by the mischievous boy.
The politician needs persuaded constituents to vote for them in the upcoming election.
The educator needs informed opinions about standardized testing before writing up a new policy.
The ballet dancer needs featured in the upcoming performance.
The competitors need impressed judges during the school talent show.
The dance troupe came to set up their equipment.
The presenter needs prepped meals to go with the meeting next week.
The high school student needs tutored before the big math exam.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

List 3: 80-20 Distribution, *Wants* Training

The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The parents completely disagreed with the new regulations.
The unpopular anthropology professor was finally going to retire.
The chef wants praised for her extraordinary recipe for chicken soup.
The roofer got a terrible sunburn from being outside all day.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The package arrived too late to be of any use.
The cardio instructor wants energized for the morning class.
The girls on the basketball team tried to practice all summer.
The salesman wants updated information before the end of the quarter.
The cyclist had to train throughout the winter so he moved to Hawaii.
The injured soccer player wants treated by the team doctor.
The new student disappeared after only three days of school.
The new experiment was the source of a great deal of excitement in the lab.
The wedding had to be rescheduled because of a hurricane.
The doctor wants rested before the surgery tomorrow.
The children in the park could be heard three blocks away.
The pilots flew over the city where they had just had a wonderful weekend.
The valiant hero wants recognized for his courageous actions.
The runners were in much better shape in the fall than in the winter.
All the undergraduates in the class had trouble keeping up.
The adventurer wants glorified songs of his achievements.
The textbooks were too expensive for most of the students.
The writer wants inspired so that they can create a masterpiece.
The lawnmower did not always function properly when the grass was wet.
The term papers from the previous semester were beginning to accumulate on the teacher’s desk.

The research assistant wants rewarded for all their hard work.
The teachers had to move their classes online due to a pandemic.
All the guitarists learned to play when they were teenagers.
The teacher wants appreciated for putting together the school curriculum.
The candles on the birthday cake were blown out in seconds.
The nurse wants disinfected needles placed in their respective drawer.
The real estate agent blundered when he revealed the house's plumbing problems.
The indoor plants dried out due to lack of proper watering.
The brightly colored parrot wants fed because she has been hungry for days.
The leader of the gambling ring was always mistrustful of his bodyguards.
Each of the divers had a strict regimen so that they would be prepared for the swim meet.
The landlord wants reimbursed for the damages to the property.
The school principal had to work constantly all summer dealing with paperwork.
The library was open to all members of the community since it was supported by tax dollars.
The students went on a trip to Paris one summer to improve their language skills.
The businesswoman wants prepared for the presentation.
The street lamps usually came on automatically just before dark.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The workers want paid for completing construction.
The sunburned boys who were fed the hot dogs got a stomach ache.
The school board wants pleased parents so that they can get more funding from the town.
The university's math courses were among the nation's most rigorous.
The customer wants served before everyone else in the restaurant.
The people downtown are frustrated by the lack of available parking.
The company's health plan did not cover even the most basic health services.
The cute baby wants held because he is feeling uneasy.
The landscaper boasted of his achievements constantly.
The physics professor at the university was finally going to retire.
The basketball game ended with the home team missing the winning shot.
The prospective students want accepted to the graduate program.
The university students sometimes move into the dormitories as early as August.
Many of the soldiers were looking forward to going home for the winter holidays.
The sheep want sheared before summer arrives in two months.
The angry customers decided to leave the restaurant.
Each of the cab drivers had their own favorite route to get to the airport.
The power plant deserved more attention from the candidates during the election.
The mayor wants respected after calming down the crowds.
The eccentric professor always inspired his students to think critically about their work.
The official wants translated documents for the court case.
The quilts were sold by the side of the road for ten dollars.
The car salesman waited anxiously for more customers.
The general wants honored for his wartime heroics six years ago.
The valuable lamp was broken by the mischievous boy.
The spy was unable to cross the field without being seen.
The engineers at the plant had to wear helmets when they went near the machines.
The ballet dancer wants featured in the upcoming performance.

The priceless ceramic sculpture had to sit on the top shelf of the lawyer's office.
The dance troupe came to set up their equipment.
The wealthy bankers liked to frequent the bars downtown.
The high school student wants tutored before the big math exam.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

List 4: 40-60 Distribution, *Wants* Training
The storekeepers were afraid that riots would ensue after the home team won the tournament.
The chess match lasted for hours and finally ended in a stale mate.
The board directors want accomplished doctors to make up most of the hospital staff.
The unpopular anthropology professor was finally going to retire.
The chef wants praised for her extraordinary recipe for chicken soup.
The soccer coach wants motivated athletes for the team.
The shoppers love to spend all day at the mall on the weekends.
The coffee shop was a popular hangout for political activists.
The director wants nominated actors to attend the exclusive party after the award ceremony.
The cardio instructor wants energized for the morning class.
The girls on the basketball team tried to practice all summer.
The salesman wants updated information before the end of the quarter.
The cyclist had to train throughout the winter so he moved to Hawaii.
The injured soccer player wants treated by the team doctor.
The university dean wants talented professors to head up the psychology undergraduate program.
The new experiment was the source of a great deal of excitement in the lab.
The principal wants empowered students to take action within the community.
The doctor wants rested before the surgery tomorrow.
The competitive swimmer wants dried towels for after swim practice.
The pilots flew over the city where they had just had a wonderful weekend.
The valiant hero wants recognized for his courageous actions.
The runners were in much better shape in the fall than in the winter.
The children want brushed hair before going to school.
The adventurer wants glorified songs of his achievements.
The textbooks were too expensive for most of the students.
The writer wants inspired so that they can create a masterpiece.
The diver wants certified lifeguards keeping watch over the beach.
The term papers from the previous semester were beginning to accumulate on the teacher’s desk.
The research assistant wants rewarded for all their hard work.
The teachers had to move their classes online due to a pandemic.
The employer wants determined applicants for the vacant position.
The teacher wants appreciated for putting together the school curriculum.
The candles on the birthday cake were blown out in seconds.
The nurse wants disinfected needles placed in their respective drawer.
The real estate agent blundered when he revealed the house's plumbing problems.
The conductor wants skilled musicians playing in the orchestra.
The brightly colored parrot wants fed because she has been hungry for days.
The leader of the gambling ring was always mistrustful of his bodyguards.

The veterinarian wants behaved pets at their practice.
The landlord wants reimbursed for the damages to the property.
The kids want animated movies shown at the theater during their spring break.
The library was open to all members of the community since it was supported by tax dollars.
The kindergarten teacher wants excited kids to attend class online.
The businesswoman wants prepared for the presentation.
The actor wants rehearsed performances scheduled before the opening of the show.
The foreign ambassadors arrived to the meeting surrounded by security guards.
The workers want paid for completing construction.
The sunburned boys who were fed the hot dogs got a stomach ache.
The school board wants pleased parents so that they can get more funding from the town.
The university's math courses were among the nation's most rigorous.
The customer wants served before everyone else in the restaurant.
The people downtown are frustrated by the lack of available parking.
The lawyer wants approved papers by tomorrow morning.
The cute baby wants held because he is feeling uneasy.
The temporary worker wants assigned hours before the holidays.
The physics professor at the university was finally going to retire.
The bride and groom want recorded video of their wedding.
The prospective students want accepted to the graduate program.
The university students sometimes move into the dormitories as early as August.
The high school student wants appointed study hours for the upcoming exam.
The sheep want sheared before summer arrives in two months.
The angry customers decided to leave the restaurant.
The hotel manager wants satisfied guests at each of their hotels.
The artist wants developed photographs before the gallery opens in two days.
The mayor wants respected after calming down the crowds.
The eccentric professor always inspired his students to think critically about their work.
The official wants translated documents for the court case.
The quilts were sold by the side of the road for ten dollars.
The young agent wants married couples to lease the nice apartment units.
The general wants honored for his wartime heroics six years ago.
The valuable lamp was broken by the mischievous boy.
The politician wants persuaded constituents to vote for them in the upcoming election.
The educator wants informed opinions about standardized testing before writing up a new policy.
The ballet dancer wants featured in the upcoming performance.
The competitors want impressed judges during the school talent show.
The dance troupe came to set up their equipment.
The presenter wants prepped meals to go with the meeting next week.
The high school student wants tutored before the big math exam.
The former drug addict's memoirs were met with critical acclaim.
The new student caught everyone's attention when he came into the room.

APPENDIX D: POST-EXPERIMENT QUESTIONNAIRE

Did you think there was anything odd about the sentences you read?
Yes No

If yes, can you describe what was odd or give an example of something odd you saw?

Some people say *The car needs washed*, instead of *The car needs <u>to be</u> washed*.

Prior to this experiment, how often did you hear sentences like The car needs washed?:

- Never
- Rarely
- Sometimes
- Often

Have you ever lived in Pennsylvania, USA?
Yes No

Select the option that best describes your situation living in Pennsylvania:

- Lived there for a short time
- Grew up there but no longer live there
- Currently live there but moved there as an adult
- Lived there for a long time but no longer live there
- Spent entire life there

Have you ever lived in Colorado, USA?
Yes No

Select the option that best describes your situation living in Colorado:

- Lived there for a short time
- Grew up there but no longer live there
- Currently live there but moved there as an adult
- Lived there for a long time but no longer live there
- Spent entire life there

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