

**How Black and White is Language Processing?
An Investigation into the Noisy-channel Processing of Binomials**

By

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Abstract

Abstract

1. Introduction

Humans have a great deal of flexibility when it comes to linearizing our abstract thoughts into discrete words or phrases. For example, to express uncertainty, we have a variety of options ranging from familiar expressions such as *I don't know*, to more novel expressions, such as *to me, it is uncertain*. In other words, when speaking we are faced with the decision of either accessing a holistically stored expression or generating a novel expression by combining words using knowledge of the grammar.

Traditionally, the assumption with respect to this trade off between item-specific and generative knowledge was that it is a function of a word or phrase's semantic compositionally [i.e., the degree to which the phrase's meaning could be derived from the individual words or morphemes that comprise it; Chomsky (1965); Pinker & Ullman (2002)]. For example, according to generativist theories, regular multi-morphemic words can be composed using rules of the language. As such, a word like *cats* would be generated by accessing the holistically stored word, *cat*, and then generating *cats* by using knowledge of the grammar with respect to plural formation. Similarly, multi-word phrases, such as *I don't know* would be generated by accessing each of the individual words in the phrase and then combining them.

These theories gained a great deal of traction, partially due to concerns about memory limitations. However, more recently we have learned that the brain has a much larger memory capacity than we once thought. For example, Wang et al. (2003) demonstrated that the human brain can store an upwards of 10^{8432} bits. Further, Mollica & Piantadosi (2019) estimated that the upper bound of memory that it would require to store linguistic knowledge is ten million bits of information, which is well within the estimated amount of storage that the human brain has.

As knowledge of the memory capacity of the brain increased, alternative accounts to holistic storage began gaining traction. These theories grew largely out of the phonetics literature where generativists' cookie-cutter approach to language quickly fell short. For example, Bybee (2002) demonstrated that the phonetic reduction of a sound advances more greatly in high-frequency words than low-frequency words. If words are the combination of abstract phonemes,

then the reduction of a phoneme should proliferate across every word that contains the phoneme. In other words, it's hard to account for the context-specificity of phoneme realizations without a storage mechanism that contains context-specific phonetic detail.

Similarly, in their seminal paper McMurray et al. (2008) demonstrated that people are sensitive to gradient changes of within-category voice onset timing (VOT). VOT is a measure of when the vocal chords begin flapping with respect to the production of a voiced or voiceless phoneme. While VOT is a continuous measure, it is used by English listeners to make a binary determine as to whether a sound is voiced or unvoiced. Following this, if phonemes are represented as abstract categories (e.g., just *p* or *b*), then VOT should only influence listener's perception if the change in VOT results in a change in the phoneme. That is, if two sounds vary in VOT but are still classified as *p*, participants should not be sensitive to the difference in VOT (if they're decomposing the word into abstract phonemes). However, McMurray et al. (2008) demonstrated that listeners *are* sensitive to within-category VOT. Specifically, they presented participants with words such as *barricade/parakeet*, where the initial sounds were either voiced or voiceless stops. They then systematically manipulated the VOT for the initial stop and measured the proportion of participants' fixations to the competitor. They found that within-category variability of VOT affected the proportion of fixations to the competitor, suggesting sensitivity to within-category variability in VOT.

These findings also sparked similar questions about the representations of multi-word phrases. For example, Bybee & Scheibman (1999) examined the phonetic reduction of *don't* in various contexts. They found that *don't* is more greatly reduced in *I don't know* than in lower-frequency phrases such as *I don't go*. In other words, the phonetic reduction of *I don't know* cannot be attributed to the phonetic reduction of any of the individual parts in isolation. This suggests that *I don't know* has a representation separate from the individual parts. Bybee & Scheibman (1999) showed similar results for other high-frequency phrases as well, such as *have to*, *want to*, etc. Similarly, Yi (2002) demonstrated that tensification in certain multi-word phrases in Korean is also context-specific. Specifically, in Korean certain consonants become tense when they occur after the future tense marker. Yi (2002) demonstrated that this tensification is more frequent in high-frequency phrases. The context-specificity of the phonetic reduction of multi-word phrases is strong evidence for the

holistic storage of multi-word phrases.

In the Psycholinguistics literature, there has been a rich literature examining the multi-word holistic storage of binomials (Houghton & Morgan, 2023, 2024; Morgan, n.d.; Morgan & Levy, 2015, 2016a, 2016b, 2024; Siyanova-Chanturia et al., 2011). For example, Siyanova-Chanturia et al. (2011) demonstrated that binomials are read faster in their frequent order (e.g., *bread and butter*) than in their infrequent ordering (e.g., *butter and bread*). If binomials were represented and processed word-by-word then it is unclear how to account for this result since the individual words are identical across different orderings of the same binomial (i.e., the words in *cats and dogs* are the same as in *dogs and cats*).

One possibility is that humans have abstract preferences for the ordering of words in phrases (e.g., a preference for short words first). Morgan & Levy (2016a) examined this possibility by creating a corpus of binomials and annotating them for semantic and phonological constraints known to influence binomial orderings (Benor & Levy, 2006). They then created a logistic model to combine these constraints into a single generative preference value that indicated the direction and magnitude of the preference.

Morgan & Levy (2016a) further examined whether human ordering preferences are driven by these generative preferences for binomials ranging in overall frequency (where overall frequency is the total number of times a binomial occurs in either ordering, e.g., the number of times *bread and butter* occurs plus the number of times *butter and bread* occurs). Specifically, they used a self-paced reading task and had participants read binomials in sentence contexts, and recorded their reading times. They found that for low-frequency binomials, human reading times were driven primarily by generative preferences, however for high-frequency binomials human reading times were driven primarily by relative frequency (i.e., the proportion of counts in the alphabetical ordering to the nonalphabetical ordering, e.g., the proportion of counts of *bread and butter* to counts of *butter and bread*). Their results suggest that humans compose low-frequency binomials using generative knowledge of the language, however for high-frequency binomials humans store and access a holistic representation of the entire binomial.

1.1. Frequency-dependent Preference Extremity

Holistic storage also makes rich predictions about language change that have been born out in the literature. For example, there is evidence that ordering preferences become more extreme for high-frequency items relative to low-frequency items (Liu & Morgan, 2020, 2021; Morgan & Levy, 2016a). If phrases are generated compositionally without any holistic storage, it is hard to see how high-frequency phrases would become more polarized, especially binomials since both orderings contain the same words. However, this is precisely what the literature has demonstrated. For example, Morgan & Levy (2015) demonstrated that the ordering preferences of binomials are more extreme for high-frequency binomials relative to low-frequency binomials.

Additionally, Liu & Morgan (2020) demonstrated that the dative alternation (e.g., *give him the ball* vs *give the ball to him*) also shows evidence of frequency-dependent preference extremity. Specifically, they found that for high-frequency verbs, there is a stronger preference for using one dative alternation over the other than for low-frequency verbs. Similarly, Liu & Morgan (2021) examined the ordering of adjectives in adjective-adjective-noun (AAN) phrases (e.g., *dark blue sky*). They found that AAN phrases with higher overall frequency (where overall frequency is the sum of counts in either ordering) show more polarized ordering preferences.

While holistic storage is a prerequisite for frequency-dependent preference extremity, it isn't enough by itself to account for this phenomenon. That is, high-frequency binomials being stored holistically does not necessarily lead to them being used more. In addition to holistic storage, it is possible that frequency-dependent preference extremity arises as an interaction between imperfect learning and transmission across generations (Houghton & Morgan, 2024; Morgan & Levy, 2016b). Specifically, Morgan & Levy (2016b) argued that humans have a bias to regularize productions to decrease variability (Hudson Kam & Newport, 2005). It is possible that this regularization bias causes high-frequency binomials to become more polarized (i.e., more regularized). Indeed, they found that a computational model that contains a frequency-independent regularization bias does result in frequency-dependent preference extremity. They demonstrated that this is because in their model, learners rely on their priors when there isn't enough data (such as in the case of lower frequency binomials), but when they have enough data they overcome their priors,

resulting in more regularized/polarized productions.

Specifically Morgan & Levy (2016b) used a 2-alternative iterated learning paradigm (Real & Griffiths, 2009) to simulate the evolution of binomial ordering preferences across generations of speakers. In their model, a speaker first produces N binomial expressions in either ordering in proportion to their learned preferences. For the first generation of speakers, this proportion is simply the generative preference of the binomial. The learner then “hears” these N binomial expressions and updates their hypothesis about the proportion that each ordering of that binomial occurs in. This data generation process alone simply results in learner’s converging on the prior (Griffiths & Kalish, 2007), which was the generative preference value for the binomial. Thus, Morgan & Levy (2016b) introduced a frequency-independent regularization bias into their model, which pressured productions to be more regular (regardless of the frequency of the binomial). Thus, if there was not strong evidence for one ordering over the other, learners’ preferences was pulled towards the prior. If there was enough evidence, however, learners would learn a preference for the ordering of the binomial and that preference would become more regularized over time. This model resulted in frequency-dependent preference extremity arising across generations of learners.

However, while their results demonstrate that a frequency-independent regularization bias can account for frequency-dependent preference extremity, it’s unclear what process this bias is analogous to in language learning/processing.

1.2. Noisy-channel Processing

One possibility is that the frequency-independent regularization bias is a consequence of noisy-channel processing.¹

When processing language, we are faced with a great deal of noise in our environment. This can be literal noise in our environment, such as the sound of a loud city, or noise introduced by the communication device, such as static in a cellphone conversation. It can also be errors made by

¹It is worth mentioning here that in parallel to the development of noisy-channel processing theories, other accounts making similar claims also emerged (e.g., Ferreira & Patson, 2007). Many of these theories accept that language processing must allow for flexibility and it’s often difficult to disentangle them. While we take a noisy-channel approach in the present thesis, all of the claims we make are also compatible with good-enough processing theories as well, and we leave the task of disentangling the two theories to future work.

the speaker (speech errors) or by the listener (perceptual errors). Despite the abundance of noise in our environment, the language processing system appears to be quite robust to noise. One possible explanation is that people may be tracking, not simply what they are hearing, but also what they think the speaker actually intended to say (Gibson et al., 2013; Levy, 2008). Thus in some cases where people hear something implausible, they may actually think that the speaker intended to say something else, and process it as if they did say the intended utterance.

There is a great deal of evidence that people do take noise into account. First and most obviously, when a listener misses a word due to simply not hearing it (e.g., a loud noise interrupted the utterance), it very rarely causes a complete breakdown in communication. Further, Ganong (1980) demonstrated that people process a non-word as being a word under noisy conditions. Similarly, Felty et al. (n.d.) found that when listeners misperceive a word, the word that they believed to have heard is a higher frequency than the word spoken. These results suggest that in noise listeners are relying on information about the language, such as what utterances are more probable, to overcome the perceptual difficulties.

Interestingly, people will sometimes even hear a grammatical sentence and interpret the meaning differently from what they have heard due to noisy-channel processing. For example Christianson et al. (2001) found that when people read the sentence *While the man hunted the deer ran into the woods*, people will answer in the affirmative for the question *Did the man hunt the deer?* as well as the question *Did the deer run into the woods?*. People interpret this sentence as having been *While the man hunted the deer, it ran into the woods*. Levy (2008) argued that since both interpretations can arise from a single insertion, noisy-channel processing offers an explanation for this finding.

Following this, Gibson et al. (2013) formalized a noisy-channel processing model using a Bayesian framework. They modeled noisy-channel processing as a process wherein the listener estimates the probability of the speaker's intended utterance (s_i) given what they perceived (s_p , Equation 1) Specifically, the listener is modeled as a rational Bayesian who estimates the probability of the speaker's intended utterance given the perceived utterance as being proportional to the probability of the intended utterance in general times the probability of that perceived utterance given the intended utterance. This is formalized mathematically in Equation 1 where s_i is the

speaker’s intended sentence and s_p is the perceived sentence. The prior ($P(s_p|s_i)$) is the likelihood of the s_i being corrupted to s_p .

$$P(s_i|s_p) \propto P(s_i)P(s_p|s_i) \quad (1)$$

The model in Gibson et al. (2013) made several predictions. Specifically, their model predicted that comprehenders should be more likely to interpret a semantically implausible sentence (e.g., *the mother gave the candle the daughter*) as being plausible (e.g., *the mother gave the candle to the daughter*) if there is increased noise (which they accomplished by adding syntactic errors to the filler items). Their model also predicted that increasing the probability of an implausible utterance (e.g., by adding more implausible items to the fillers) should lead to an increased rate of implausible interpretations. They tested these predictions by giving participants a series of sentences, some of which were semantically implausible but had semantically plausible alternatives that participants could interpret the sentence as being. These alternatives varied in how different they were from the perceived utterances. Some of them varied from the perceived utterance by a single insertion or a single deletion, while others varied by two insertions or two deletions. By manipulating the number of semantically implausible sentences as well as the number of filler items with syntactic errors, both of the predictions that their model made were born out in experimental data that they had collected.

Given these results, Houghton & Morgan (2024) extended Morgan & Levy (2016b)’s model. Specifically, we used a 2-alternative iterated learning paradigm. In this paradigm, learners are modeled as having heard N tokens of a given binomial in either alphabetical or nonalphabetical order while updating a hypothesis with respect to the ordering preference for each binomial. In our model, the learner’s goal was to learn the ordering preferences for each binomial. Then after learning the ordering preferences, the learner then produced N tokens to the next generation. This process then repeated iteratively.

After hearing a binomial, the learner in our model updated their beliefs in proportion to what they believed the speaker’s intended ordering was, which was modeled with pseudo counts. For example, if they believed the intended utterance was A and B with 60% probability and B and

A with 40% probability, then they would add 0.6 and 0.4 to the pseudo counts for A and B and B and A respectively.²

Without a regularization bias, this model would simply result in convergence to the prior (Griffiths & Kalish, 2007), which is equivalent to the generative preference for the binomial. Thus, our model also contained a noisy-channel processing component. After hearing a binomial, the learner in our model would interpret the opposite ordering occasionally (with probability according to Equation 1). That is, if the learner hears B and A, but is confident that the intended ordering was actually A and B, they are more likely to update their beliefs as if they had heard A and B.

To help build intuition for this: suppose a learner believes there is a 60% chance that the speaker intended to say A and B, but they heard B and A. Without a noisy-channel processing component, the learner would update their belief, down-weighting the probability of A and B and up-weighting the probability of B and A. However, with noisy-channel processing, the learner may actually assume the speaker intended to say A and B (after calculating this probability according to Equation 1), but had actually misspoke and said B and A. This would then result in updating their beliefs as if they had heard A and B. For high-frequency binomials, the learner encounters the binomial more and has more opportunities to interpret B and A as A and B. However, for low-frequency binomials, the learner does not encounter the binomial as many times and has fewer opportunities. In a more extreme example, if a learner believes that there is a 90% chance that the speaker intended to say A and B and a 10% chance they had intended to say B and A, then on the few trials they hear B and A, they are very likely to assume that the speaker intended to say A and B. This would result in their beliefs about the probability of the ordering being pulled closer to 100% (since in the 10% of trials they heard B and A, the learner would assume the speaker meant A and B and subsequently update their beliefs in favor of A and B) if they hear the binomial enough times to overcome the prior beliefs.

Indeed, this is precisely the result we found in Houghton & Morgan (2024). That is, that for low-frequency binomials, the learner's belief about the intended ordering was not particularly strong and was pulled towards the prior. However, for high-frequency binomials, as the learning

²See Houghton & Morgan (2024) for a more detailed explanation of our computational model.

continued iteratively across generations, frequency-dependent preference extremity arose.

Our results in Houghton & Morgan (2024) demonstrated that a noisy-channel processing model in an iterative learning paradigm can predict frequency-dependent preference extremity. It also makes a crucial prediction: that learners sometimes hear *B and A*, but actually interpret it to be *B and A*. In the present study we explore this prediction.

1.3. Present Thesis

Houghton & Morgan (2024)'s model predicts that learners sometimes hear one binomial ordering but interpret it to be the opposite ordering. If this is the case, then it is possible that upon hearing, e.g., *white and black*, the listener actually processes it as *black and white*. There is a great deal of evidence that activating a phrase results in decreased processing time if encountering the same phrase shortly after (e.g., Tabossi & Johnson-Laird, 1980). If this is the case, then hearing *white and black* should actually speed up the processing of *black and white* more than it speeds up the processing of *white and black*. This is the prediction that we set out to test in the present study. By using a primed self-paced reading task with a mental rotation task, we examine whether *white and black* primes *black and white* more than it primes *white and black*.

2. Methods

2.1. Procedure

In order to examine the effects of noisy-channel processing on the reading times of binomials, we used a primed self-paced reading task with a mental rotation task. Specifically, participants were first presented auditorily with a prime sentence while simultaneously completing a mental rotation task. The mental rotation task involved determining whether one was a simple rotation or a mirror image of another image. The rotation was always either 0 degrees or 45 degrees. Participants were tasked with either pressing the 'f' key or the 'j' key (counter balanced between participants) to indicate that the image was either a simple rotation or a mirror image. The idea

behind the mental rotation task was that by forcing participants to multi-task they may rely more on noisy-channel processing than when they can focus solely on the prime sentences.

After listening to the prime sentence and completing the mental rotation, participants then completed a self-paced reading task. Specifically, participants were presented with a sentence word-by-word and pressed the ‘space’ key when they were ready to proceed to the next word. Reaction times for the time it took participants to press the ‘space’ key were recorded for each word. After each sentence, participants were presented with a comprehension question to test their attention. The comprehension questions were questions either about the prime sentence or the sentence they had just read.

2.2. Stimuli

Our stimuli consisted of 30 polarized binomials.³ Specifically, these were binomials that occurred more than 400,000 times (out of 323,592,921,465 tokens), calculated using the Google *n*-grams corpus (Michel et al., 2011). Additionally, they all had a relative frequency of either less than -0.30 and greater than 0.30. Relative frequency indicates which ordering is more preferred (and to what magnitude). For example, a binomial that occurs equally as many times in both orders would have a relative frequency of zero (where relative frequency ranges from -0.50 to 0.50). A relative frequency value below 0 indicates that the nonalphabetical ordering occurred more than the alphabetical ordering in corpus data, and a number above zero indicates the opposite. The magnitude of the number indicates the strength, with 0.50 indicating that the binomial occurred exclusively in alphabetical ordering and -0.50 indicated the binomial occurred exclusively in nonalphabetical ordering. Thus binomials with a relative frequency below -0.3 and above 0.3 are quite polarized in their ordering.

For each of these binomials, we created a prime and a target sentence containing the binomial in either order. Specifically, for each binomial, three prime sentences were made: one that contained the binomial in the frequent ordering (e.g., *bread and butter*), one that contained the

³Our stimuli and analyses are available at the following link: <https://github.com/znhoughton/Noisy-Channel-Binomial-Preferences>. The stimuli are also included in the appendix section (Section A).

Table 2.1: A table of our conditions.

Condition	Target Frequency	Prime Frequency	Target Binomial	Prime Binomial
1	Infrequent	Infrequent	gentlemen and ladies	gentlemen and ladies
2	Frequent	Infrequent	ladies and gentlemen	gentlemen and ladies
3	Infrequent	Frequent	gentlemen and ladies	ladies and gentlemen
4	Frequent	Frequent	ladies and gentlemen	ladies and gentlemen
5	Infrequent	Unrelated	gentlemen and ladies	Unrelated
6	Frequent	Unrelated	ladies and gentlemen	Unrelated

infrequent ordering, (*butter and bread*), and one that did not contain a binomial at all. These priming conditions are referred to as the frequent, infrequent, and unrelated primes respectively. We also made two target sentences (the sentences read during the self-paced reading task) for each binomial. The target sentences contained the binomial in either the frequent or infrequent ordering. A table demonstrating our six conditions is presented below in Table 2.1. Finally, we also included 30 filler trials, which did not contain binomials in the prime or target sentences. An example of each of our conditions is included below:

Our prime and target sentences were crossed such that each target occurred with each prime, however no participant was presented with the same binomial in more than one trial.

2.3. Participants

228 University of California, Davis undergraduate students were given course credit to participate in the study. We also recruited an additional 220 participants through Prolific. Altogether, 448 people participated in our study.

Participants were randomly presented with one of 6 conditions. Since our design is a 3 x 2 design, 6 conditions were created so that participants did not encounter the same binomial in more than one trial.

2.4. Analysis

We divided the sentences into a target and spillover region to be our region of analysis. This region included the 3 words in the binomial along with the 3 following words. We then excluded participants whose reading times on this region were less than 100ms or greater than 5000 ms (following Morgan & Levy, 2016a). We also excluded participants who had an average accuracy below 0.7 on the audio comprehension questions (the questions that asked about the auditorily presented prime). Finally, we excluded trials for which the residual reading times were outside of 2.5 standard deviations from the mean.

We then ran two Bayesian mixed-effects regression models with residual reading times as the dependent variable.⁴

For the first model, we were interested in whether a frequent prime affected the residual reading times. As such, we filtered the dataframe to include trials that contained either an unrelated or frequent prime. We then treatment coded our variables such that for the prime sentences, 0 indicated an unrelated prime and 1 indicated a frequent prime. For target sentences, 0 indicated an infrequent target while 1 indicated a frequent target. We then ran a model with residual reading time as the dependent variable, fixed-effects for prime, target, and their interaction, as well as maximal random-effects (following Barr et al., 2013).

Our second model was similar, however we were interested in how the infrequent prime affected residual reading times. As such, we filtered our dataframe to include trials that contained either the unrelated or infrequent prime. We then treatment coded our variables such that 0 indicated an unrelated prime and 1 indicated an infrequent prime.

Our model syntax was the same for both models, as mentioned previously the difference was the levels of the variables included in the data.

⁴A pre-registration of our study is available at the following link: <https://aspredicted.org/t324-swgk.pdf>.

$$\begin{aligned} \text{Residual Reading Time} \sim & \text{Intercept} + \text{prime freq} * \text{target freq} \\ & + (\text{prime freq} * \text{target freq} | \text{Item}) + (\text{prime freq} * \text{target freq} | \text{participant}) \end{aligned} \quad (2)$$

3. Results

We first examined whether a frequent prime facilitated the reading of the frequent ordering of the binomial more than the reading time of the infrequent ordering. Following Houghton et al. (2024), in addition to reporting the estimates we also report the percentage of posterior samples greater than zero. Bayesian statistics don't force us into a binary interpretation of significance or non-significance, by reporting the percentage of posterior samples greater than zero we are able to interpret the results in a more nuanced manner.

The results are presented in Table 3.1 and visualized in Figure 3.1. Since prime and target types were treatment coded, the Intercept represents the estimated reading times for unrelated prime sentences with an infrequent target sentence. Coefficient estimates represent the distance from the Intercept. Although the credible interval crosses zero, over 93% of the posterior samples for the effect of frequent prime were greater than zero, suggesting that for not-frequent targets, the frequent prime resulted in slower reading times than the unrelated prime. Similarly, over 93% of the posterior samples for frequent target were less than zero, suggesting that for unrelated primes, the frequent target was read faster. Finally, about 90% of the samples for the interaction effect were less than zero, suggesting that the difference between the reading times in the unrelated prime condition and the reading times in the frequent prime condition were larger for infrequent targets than frequent targets. In other words, the frequent prime speeds up the reading times for the frequent ordering of the binomial more than the infrequent ordering of the binomial.

Next we examined whether the infrequent prime speeds up the infrequent ordering of the binomial more than the frequent ordering. If readers are engaged in noisy-channel processing when listening to the prime, they may actually activate *bread and butter* when they hear *butter and*

Table 3.1: Results of the statistical model for the frequent vs unrelated prime.

	Estimate	Est.Error	Q2.5	Q97.5	% Samples > 0
Intercept	-169.01	20.59	-209.40	-128.03	0.00
Frequent Prime	25.76	17.04	-7.10	59.63	93.92
Frequent Target	-25.70	15.09	-56.01	3.41	4.32
Frequent Prime:Frequent Target	-23.91	19.30	-63.64	12.47	10.19

Table 3.2: Results of the statistical model for the infrequent vs unrelated prime.

	Estimate	Est.Error	Q2.5	Q97.5	% Samples > 0
Intercept	-173.52	20.78	-214.07	-132.06	0.00
Infrequent Prime	7.48	14.00	-19.71	35.31	70.50
Frequent Target	-13.94	14.61	-43.68	13.84	16.81
Infrequent Prime:Frequent Target	24.57	19.39	-11.57	64.51	90.53

bread. This would result in the infrequent prime speeding up the *frequent* ordering of the binomial more than the infrequent ordering.

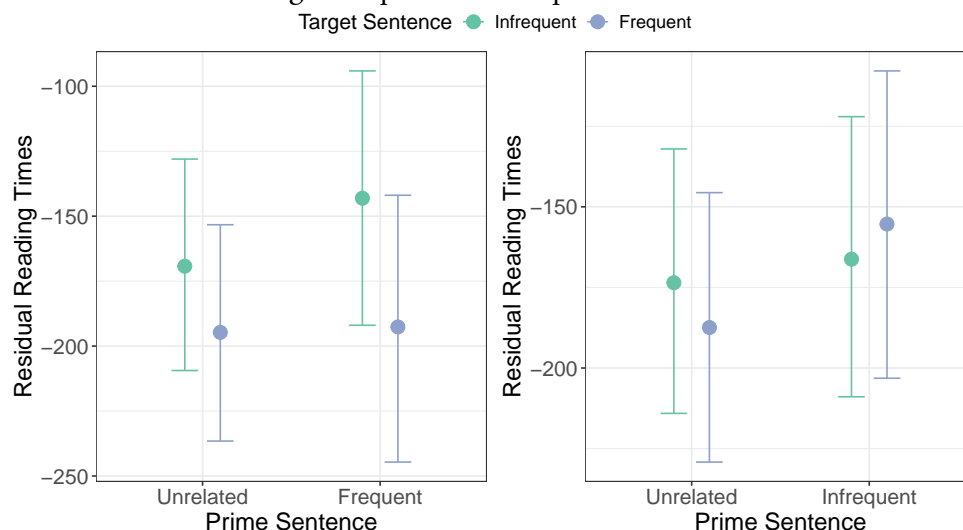
The results are presented in Table 3.2 and visualized in Figure 3.1. Similar to the previous model, since prime and target types were treatment coded, the Intercept represents the estimated reading times for unrelated prime sentences with an infrequent target sentence. Coefficient estimates represent the distance from the Intercept. We find no meaningful main-effect for infrequent primes or frequent targets, but we do find a meaningful interaction effect. While the credible interval crosses zero, over 90% of the posterior samples were greater than zero. The results suggest that the infrequent prime speeds up reading for the infrequent target more than the frequent target.

4. Discussion

Our results demonstrate that both the frequent and infrequent ordering of a given binomial speeds up the reading times of the respective ordering. That is, priming the frequent ordering speeds up the reading of the frequent ordering, and priming the infrequent ordering speeds up the reading of the infrequent ordering.

Our model in Houghton & Morgan (2024) predicted the opposite result, that hearing the infrequent binomial ordering might actually result in learner's accessing the frequent ordering of

Figure 3.1: Plot of our model estimates. The x-axis represents whether the prime was unrelated, frequent, or infrequent. The y-axis corresponds to the residual reading times. Color indicates whether the target was infrequent (green) or frequent (blue). The left plot compares unrelated to frequent primes, the right plot compares unrelated to infrequent primes. The result suggest that the primed ordering is read faster regardless of whether the binomial ordering is frequent or infrequent.



the binomial. One possibility is that the binomials are undergoing noisy-channel processing, but that the effects of noisy-channel processing are higher-level. For example, while the listener may be confident and potentially even interpret the sentence as containing the frequent ordering of the binomial, they still heard the acoustics of *butter and bread* which primes the reading of *butter and bread* more than *bread and butter*. It is possible that noisy-channel processing doesn't result in priming effects.

On the other hand, it is also possible that binomials are not undergoing noisy-channel processing in this manner. There are a few possible explanations for why this might be. The first is that hearing polarized binomials in the opposite ordering is quite surprising. That is, hearing *butter and bread* is pretty surprising as a listener. It is possible that hearing *butter and bread* then draws attention to itself by nature of being surprising, and thus the listener is confident that they did infact hear *butter and bread*. This would explain why there is no priming of *bread and butter*.

It's also possible that the size of the units matter. Much of the literature on noisy-channel processing involves small prepositions being inserted or deleted. However in our case, many of the binomials contain many letters/sounds. It is possible that listeners are more likely to assume that the speaker forgot to say a preposition, such as *in* or *up*, than assuming that the speaker acciden-

tally swapped two multi-syllabic words (e.g., in the case of *gentlemen and ladies* instead of *ladies and gentlemen*). Although, this seems less likely since Poppels & Levy (2016) found evidence that people do interpret semantically implausible sentences as being semantically plausible even if the semantically plausible interpretation requires positing a substitution.

Finally, it's possible that semantic plausibility also plays a large role in noisy-channel processing. That is, both orders of binomials are semantically plausible. It is simply the case that one is more frequent than the other. It is possible that semantic implausibility is a pre-requisite to noisy-channel processing, even if an utterance is low-frequency.

If it is the case, however, that the polarization seen in high-frequency binomials isn't a result of noisy-channel processing, however, then how does frequency-dependent preference extremity arise? One possibility is that it is a result of accessibility effects. For example, Harmon & Kapatsinski (2017) demonstrated that as a form becomes more frequent, it becomes more likely to be re-used to express a novel meaning. Similarly, it is possible when speakers are producing a novel sentence, they reach for the more frequent form of the binomial simply because it is more accessible.

In summary, the present results provide evidence against a noisy-channel processing account of frequency-dependent preference extremity. We find that the infrequent ordering of a binomial does not prime the frequent ordering of a binomial, which would be expected under a noisy-channel processing account. It is possible that either noisy-channel processing happens at a higher level, or that frequency-dependent preference extremity of binomials is not a consequence of noisy-channel processing.

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Appendix

A. Full List of Stimuli

Our full stimuli list is included below.

Table A.1: Full set of stimuli.

Binomial	RelFreq	GenPref	PrimeType	SentenceType	Sentence	Prime
gentlemen and ladies	-0.4086472	0.5176319	alphabetical	Sentence (alphabetical)	+ The hostess in the venue lead the gentlemen and ladies to their respective tables.	The event was attended by both gentlemen and ladies dressed in elegant attire.
gentlemen and ladies	-0.4086472	0.5176319	alphabetical	Sentence (nonalphabetical)	+ The hostess in the venue lead the ladies and gentlemen to their respective tables.	The event was attended by both gentlemen and ladies dressed in elegant attire.
gentlemen and ladies	-0.4086472	0.5176319	nonalphabetical	Sentence (alphabetical)	+ The hostess in the venue lead the gentlemen and ladies to their respective tables.	The event was attended by both ladies and gentlemen dressed in elegant attire.
gentlemen and ladies	-0.4086472	0.5176319	nonalphabetical	Sentence (nonalphabetical)	+ The hostess in the venue lead the ladies and gentlemen to their respective tables.	The event was attended by both ladies and gentlemen dressed in elegant attire.
gentlemen and ladies	-0.4086472	0.5176319	unrelated	Sentence (alphabetical)	+ The hostess in the venue lead the gentlemen and ladies to their respective tables.	The snow covered the town in a blanket of white, transforming it into a winter wonderland.
gentlemen and ladies	-0.4086472	0.5176319	unrelated	Sentence (nonalphabetical)	+ The hostess in the venue lead the ladies and gentlemen to their respective tables.	The snow covered the town in a blanket of white, transforming it into a winter wonderland.
fruits and vegetables	0.3501051	0.6085325	alphabetical	Sentence (alphabetical)	+ Growing up, Paul ate his fruits and vegetables everyday at each meal.	A healthy diet includes a balance of fruits and vegetables for essential nutrients.
fruits and vegetables	0.3501051	0.6085325	alphabetical	Sentence (nonalphabetical)	+ Growing up, Paul ate his vegetables and fruits everyday at each meal.	A healthy diet includes a balance of fruits and vegetables for essential nutrients.
fruits and vegetables	0.3501051	0.6085325	nonalphabetical	Sentence (alphabetical)	+ Growing up, Paul ate his fruits and vegetables everyday at each meal.	A healthy diet includes a balance of vegetables and fruits for essential nutrients.
fruits and vegetables	0.3501051	0.6085325	nonalphabetical	Sentence (nonalphabetical)	+ Growing up, Paul ate his vegetables and fruits everyday at each meal.	A healthy diet includes a balance of vegetables and fruits for essential nutrients.
fruits and vegetables	0.3501051	0.6085325	unrelated	Sentence (alphabetical)	+ Growing up, Paul ate his fruits and vegetables everyday at each meal.	The orchestra's music filled the hall, sending chills down the audience's spines.
fruits and vegetables	0.3501051	0.6085325	unrelated	Sentence (nonalphabetical)	+ Growing up, Paul ate his vegetables and fruits everyday at each meal.	The orchestra's music filled the hall, sending chills down the audience's spines.
blood and flesh	-0.4736040	0.4690761	alphabetical	Sentence (alphabetical)	+ Although Rhonda was not Nick's blood and flesh he considered her family.	The battle left marks of blood and flesh on the ground, a grim reminder of its toll.
blood and flesh	-0.4736040	0.4690761	alphabetical	Sentence (nonalphabetical)	+ Although Rhonda was not Nick's flesh and blood he considered her family.	The battle left marks of blood and flesh on the ground, a grim reminder of its toll.
blood and flesh	-0.4736040	0.4690761	nonalphabetical	Sentence (alphabetical)	+ Although Rhonda was not Nick's blood and flesh he considered her family.	The battle left marks of flesh and blood on the ground, a grim reminder of its toll.
blood and flesh	-0.4736040	0.4690761	nonalphabetical	Sentence (nonalphabetical)	+ Although Rhonda was not Nick's flesh and blood he considered her family.	The battle left marks of flesh and blood on the ground, a grim reminder of its toll.
blood and flesh	-0.4736040	0.4690761	unrelated	Sentence (alphabetical)	+ Although Rhonda was not Nick's blood and flesh he considered her family.	With a deep breath, she stepped onto the stage, her heart pounding in her chest.
blood and flesh	-0.4736040	0.4690761	unrelated	Sentence (nonalphabetical)	+ Although Rhonda was not Nick's flesh and blood he considered her family.	With a deep breath, she stepped onto the stage, her heart pounding in her chest.
father and son	0.4679236	0.5278980	alphabetical	Sentence (alphabetical)	+ Eric enjoys watching movies with his father and son so much that he goes often.	The bond between father and son grew deeper with each passing year.
father and son	0.4679236	0.5278980	alphabetical	Sentence (nonalphabetical)	+ Eric enjoys watching movies with his son and father so much that he goes often.	The bond between father and son grew deeper with each passing year.
father and son	0.4679236	0.5278980	nonalphabetical	Sentence (alphabetical)	+ Eric enjoys watching movies with his father and son so much that he goes often.	The bond between son and father grew deeper with each passing year.
father and son	0.4679236	0.5278980	nonalphabetical	Sentence (nonalphabetical)	+ Eric enjoys watching movies with his son and father so much that he goes often.	The bond between son and father grew deeper with each passing year.
father and son	0.4679236	0.5278980	unrelated	Sentence (alphabetical)	+ Eric enjoys watching movies with his father and son so much that he goes often.	The dog wagged its tail eagerly, hoping for a treat.
father and son	0.4679236	0.5278980	unrelated	Sentence (nonalphabetical)	+ Eric enjoys watching movies with his son and father so much that he goes often.	The dog wagged its tail eagerly, hoping for a treat.
place and time	-0.3613231	0.5553676	alphabetical	Sentence (alphabetical)	+ Finding a place and time for the meeting was very difficult.	Success in art depends on the right combination of place and time.
place and time	-0.3613231	0.5553676	alphabetical	Sentence (nonalphabetical)	+ Finding a time and place for the meeting was very difficult.	Success in art depends on the right combination of place and time.
place and time	-0.3613231	0.5553676	nonalphabetical	Sentence (alphabetical)	+ Finding a place and time for the meeting was very difficult.	Success in art depends on the right combination of time and place.
place and time	-0.3613231	0.5553676	nonalphabetical	Sentence (nonalphabetical)	+ Finding a time and place for the meeting was very difficult.	Success in art depends on the right combination of time and place.

place and time	-0.3613231	0.5553676	unrelated	Sentence (alphabetical)	+ Finding a place and time for the meeting was very difficult.	A gentle breeze rustled the leaves, carrying the scent of jasmine through the air.
place and time	-0.3613231	0.5553676	unrelated	Sentence (nonalphabetical)	+ Finding a time and place for the meeting was very difficult.	A gentle breeze rustled the leaves, carrying the scent of jasmine through the air.
arts and sciences	0.4544575	0.4933751	alphabetical	Sentence (alphabetical)	+ Jessica couldn't decide between studying arts and sciences at her time in college.	A well-rounded education often includes a balance of arts and sciences.
arts and sciences	0.4544575	0.4933751	alphabetical	Sentence (nonalphabetical)	+ Jessica couldn't decide between studying sciences and arts at her time in college.	A well-rounded education often includes a balance of arts and sciences.
arts and sciences	0.4544575	0.4933751	nonalphabetical	Sentence (alphabetical)	+ Jessica couldn't decide between studying arts and sciences at her time in college.	A well-rounded education often includes a balance of sciences and arts.
arts and sciences	0.4544575	0.4933751	nonalphabetical	Sentence (nonalphabetical)	+ Jessica couldn't decide between studying sciences and arts at her time in college.	A well-rounded education often includes a balance of sciences and arts.
arts and sciences	0.4544575	0.4933751	unrelated	Sentence (alphabetical)	+ Jessica couldn't decide between studying arts and sciences at her time in college.	The library was silent, except for the occasional sound of pages turning.
arts and sciences	0.4544575	0.4933751	unrelated	Sentence (nonalphabetical)	+ Jessica couldn't decide between studying sciences and arts at her time in college.	The library was silent, except for the occasional sound of pages turning.
development and research	-0.4807498	0.2293127	alphabetical	Sentence (alphabetical)	+ Emily was in development and research but eventually decided to leave.	Many years of development and research went into the company's new product.
development and research	-0.4807498	0.2293127	alphabetical	Sentence (nonalphabetical)	+ Emily was in research and development but eventually decided to leave.	Many years of development and research went into the company's new product.
development and research	-0.4807498	0.2293127	nonalphabetical	Sentence (alphabetical)	+ Emily was in development and research but eventually decided to leave.	Many years of research and development went into the company's new product.
development and research	-0.4807498	0.2293127	nonalphabetical	Sentence (nonalphabetical)	+ Emily was in research and development but eventually decided to leave.	Many years of research and development went into the company's new product.
development and research	-0.4807498	0.2293127	unrelated	Sentence (alphabetical)	+ Emily was in development and research but eventually decided to leave.	His suitcase was packed with essentials and a few souvenirs from his last adventure.
development and research	-0.4807498	0.2293127	unrelated	Sentence (nonalphabetical)	+ Emily was in research and development but eventually decided to leave.	His suitcase was packed with essentials and a few souvenirs from his last adventure.
law and order	0.4852173	0.8870849	alphabetical	Sentence (alphabetical)	+ There was a lack of law and order that caused some chaos.	The mayor promised to restore law and order to the troubled neighborhoods.
law and order	0.4852173	0.8870849	alphabetical	Sentence (nonalphabetical)	+ There was a lack of order and law that caused some chaos.	The mayor promised to restore law and order to the troubled neighborhoods.
law and order	0.4852173	0.8870849	nonalphabetical	Sentence (alphabetical)	+ There was a lack of law and order that caused some chaos.	The mayor promised to restore order and law to the troubled neighborhoods.
law and order	0.4852173	0.8870849	nonalphabetical	Sentence (nonalphabetical)	+ There was a lack of order and law that caused some chaos.	The mayor promised to restore order and law to the troubled neighborhoods.
law and order	0.4852173	0.8870849	unrelated	Sentence (alphabetical)	+ There was a lack of law and order that caused some chaos.	She took a long walk through the city, marveling at the towering skyscrapers.
law and order	0.4852173	0.8870849	unrelated	Sentence (nonalphabetical)	+ There was a lack of order and law that caused some chaos.	She took a long walk through the city, marveling at the towering skyscrapers.
mr. and mrs.	0.4980908	0.6408346	alphabetical	Sentence (alphabetical)	+ The couple call each other mr. and mrs. Smith even though they aren't married.	The invitation was addressed to Mr. and Mrs. Peterson, inviting them to the gala.
mr. and mrs.	0.4980908	0.6408346	alphabetical	Sentence (nonalphabetical)	+ The couple call each other mrs. and mr. Smith even though they aren't married.	The invitation was addressed to Mr. and Mrs. Peterson, inviting them to the gala.
mr. and mrs.	0.4980908	0.6408346	nonalphabetical	Sentence (alphabetical)	+ The couple call each other mr. and mrs. Smith even though they aren't married.	The invitation was addressed to Mrs. and Mr. Peterson, inviting them to the gala.
mr. and mrs.	0.4980908	0.6408346	nonalphabetical	Sentence (nonalphabetical)	+ The couple call each other mrs. and mr. Smith even though they aren't married.	The invitation was addressed to Mrs. and Mr. Peterson, inviting them to the gala.
mr. and mrs.	0.4980908	0.6408346	unrelated	Sentence (alphabetical)	+ The couple call each other mr. and mrs. Smith even though they aren't married.	They watched the fireworks explode in the night sky, their faces lit up with excitement.
mr. and mrs.	0.4980908	0.6408346	unrelated	Sentence (nonalphabetical)	+ The couple call each other mrs. and mr. Smith even though they aren't married.	They watched the fireworks explode in the night sky, their faces lit up with excitement.
men and women	0.4064281	0.7288978	alphabetical	Sentence (alphabetical)	+ Jen thought that the men and women in her dance class were all very talented.	The disparity between the wages of men and women in the workforce is a major concern for many.
men and women	0.4064281	0.7288978	alphabetical	Sentence (nonalphabetical)	+ Jen thought that the women and men in her dance class were all very talented.	The disparity between the wages of men and women in the workforce is a major concern for many.
men and women	0.4064281	0.7288978	nonalphabetical	Sentence (alphabetical)	+ Jen thought that the men and women in her dance class were all very talented.	The disparity between the wages of men and women in the workforce is a major concern for many.
men and women	0.4064281	0.7288978	nonalphabetical	Sentence (nonalphabetical)	+ Jen thought that the women and men in her dance class were all very talented.	The disparity between the wages of men and women in the workforce is a major concern for many.
men and women	0.4064281	0.7288978	unrelated	Sentence (alphabetical)	+ Jen thought that the men and women in her dance class were all very talented.	The cafe was cozy, with soft music playing and the smell of fresh pastries in the air.

men and women	0.4064281	0.7288978	unrelated	Sentence (nonalphabetical)	+ Jen thought that the women and men in her dance class were all very talented.	The cafe was cozy, with soft music playing and the smell of fresh pastries in the air.
money and time	-0.3966303	0.3490212	alphabetical	Sentence (alphabetical)	+ The amount of money and time required to fix it made it quite the project.	Managing money and time effectively is key to achieving financial goals.
money and time	-0.3966303	0.3490212	alphabetical	Sentence (nonalphabetical)	+ The amount of time and money required to fix it made it quite the project.	Managing money and time effectively is key to achieving financial goals.
money and time	-0.3966303	0.3490212	nonalphabetical	Sentence (alphabetical)	+ The amount of money and time required to fix it made it quite the project.	Managing time and money effectively is key to achieving financial goals.
money and time	-0.3966303	0.3490212	nonalphabetical	Sentence (nonalphabetical)	+ The amount of time and money required to fix it made it quite the project.	Managing time and money effectively is key to achieving financial goals.
money and time	-0.3966303	0.3490212	unrelated	Sentence (alphabetical)	+ The amount of money and time required to fix it made it quite the project.	She wrapped the scarf around her neck, bracing herself against the winter chill.
money and time	-0.3966303	0.3490212	unrelated	Sentence (nonalphabetical)	+ The amount of time and money required to fix it made it quite the project.	She wrapped the scarf around her neck, bracing herself against the winter chill.
brother and sister	0.3382719	0.6344815	alphabetical	Sentence (alphabetical)	+ Paul wants to spend time with his brother and sister because they are cool.	The brother and sister shared a bond that no distance could weaken.
brother and sister	0.3382719	0.6344815	alphabetical	Sentence (nonalphabetical)	+ Paul wants to spend time with his sister and brother because they are cool.	The brother and sister shared a bond that no distance could weaken.
brother and sister	0.3382719	0.6344815	nonalphabetical	Sentence (alphabetical)	+ Paul wants to spend time with his brother and sister because they are cool.	The sister and brother shared a bond that no distance could weaken.
brother and sister	0.3382719	0.6344815	nonalphabetical	Sentence (nonalphabetical)	+ Paul wants to spend time with his sister and brother because they are cool.	The sister and brother shared a bond that no distance could weaken.
brother and sister	0.3382719	0.6344815	unrelated	Sentence (alphabetical)	+ Paul wants to spend time with his brother and sister because they are cool.	The cat curled up on the windowsill, basking in a patch of warm sunlight.
brother and sister	0.3382719	0.6344815	unrelated	Sentence (nonalphabetical)	+ Paul wants to spend time with his sister and brother because they are cool.	The cat curled up on the windowsill, basking in a patch of warm sunlight.
husband and wife	0.4745981	0.5027550	alphabetical	Sentence (alphabetical)	+ Michelle was surprised to learn that the husband and wife were getting a divorce.	The couple was too young to be husband and wife, in their parents' opinion.
husband and wife	0.4745981	0.5027550	alphabetical	Sentence (nonalphabetical)	+ Michelle was surprised to learn that the wife and husband were getting a divorce.	The couple was too young to be husband and wife, in their parents' opinion.
husband and wife	0.4745981	0.5027550	nonalphabetical	Sentence (alphabetical)	+ Michelle was surprised to learn that the husband and wife were getting a divorce.	The couple was too young to be wife and husband, in their parents' opinion.
husband and wife	0.4745981	0.5027550	nonalphabetical	Sentence (nonalphabetical)	+ Michelle was surprised to learn that the wife and husband were getting a divorce.	The couple was too young to be wife and husband, in their parents' opinion.
husband and wife	0.4745981	0.5027550	unrelated	Sentence (alphabetical)	+ Michelle was surprised to learn that the husband and wife were getting a divorce.	The old house creaked and groaned with every gust of wind.
husband and wife	0.4745981	0.5027550	unrelated	Sentence (nonalphabetical)	+ Michelle was surprised to learn that the wife and husband were getting a divorce.	The old house creaked and groaned with every gust of wind.
north and south	0.4390121	0.6108187	alphabetical	Sentence (alphabetical)	+ The family moved north and south a couple of times.	The campaign has supporters from both north and south regions.
north and south	0.4390121	0.6108187	alphabetical	Sentence (nonalphabetical)	+ The family moved south and north a couple of times.	The campaign has supporters from both north and south regions.
north and south	0.4390121	0.6108187	nonalphabetical	Sentence (alphabetical)	+ The family moved north and south a couple of times.	The campaign has supporters from both south and north regions.
north and south	0.4390121	0.6108187	nonalphabetical	Sentence (nonalphabetical)	+ The family moved south and north a couple of times.	The campaign has supporters from both south and north regions.
north and south	0.4390121	0.6108187	unrelated	Sentence (alphabetical)	+ The family moved north and south a couple of times.	The antique store was filled with treasures from a bygone era.
north and south	0.4390121	0.6108187	unrelated	Sentence (nonalphabetical)	+ The family moved south and north a couple of times.	The antique store was filled with treasures from a bygone era.
error and trial	-0.4995134	0.1682363	alphabetical	Sentence (alphabetical)	+ Hal solved the math problem by error and trial because he was lazy.	Sometimes it feels like trial and error is the only way to learn.
error and trial	-0.4995134	0.1682363	alphabetical	Sentence (nonalphabetical)	+ Hal solved the math problem by trial and error because he was lazy.	Sometimes it feels like trial and error is the only way to learn.
error and trial	-0.4995134	0.1682363	nonalphabetical	Sentence (alphabetical)	+ Hal solved the math problem by error and trial because he was lazy.	Sometimes it feels like error and trial is the only way to learn.
error and trial	-0.4995134	0.1682363	nonalphabetical	Sentence (nonalphabetical)	+ Hal solved the math problem by trial and error because he was lazy.	Sometimes it feels like error and trial is the only way to learn.
error and trial	-0.4995134	0.1682363	unrelated	Sentence (alphabetical)	+ Hal solved the math problem by error and trial because he was lazy.	The aroma of freshly baked bread drifted from the kitchen, inviting everyone inside.
error and trial	-0.4995134	0.1682363	unrelated	Sentence (nonalphabetical)	+ Hal solved the math problem by trial and error because he was lazy.	The aroma of freshly baked bread drifted from the kitchen, inviting everyone inside.

black and white	0.3322019	0.4175274	alphabetical	Sentence (alphabetical)	+ Dalmatians found in colors other than black and white are really quite unusual.	The film is shot entirely in black and white, giving it a timeless quality.
black and white	0.3322019	0.4175274	alphabetical	Sentence (nonalphabetical)	+ Dalmatians found in colors other than white and black are really quite unusual.	The film is shot entirely in black and white, giving it a timeless quality.
black and white	0.3322019	0.4175274	nonalphabetical	Sentence (alphabetical)	+ Dalmatians found in colors other than black and white are really quite unusual.	The film is shot entirely in white and black, giving it a timeless quality.
black and white	0.3322019	0.4175274	nonalphabetical	Sentence (nonalphabetical)	+ Dalmatians found in colors other than white and black are really quite unusual.	The film is shot entirely in white and black, giving it a timeless quality.
black and white	0.3322019	0.4175274	unrelated	Sentence (alphabetical)	+ Dalmatians found in colors other than black and white are really quite unusual.	He watched the rain tap against the window, lost in thought.
black and white	0.3322019	0.4175274	unrelated	Sentence (nonalphabetical)	+ Dalmatians found in colors other than white and black are really quite unusual.	He watched the rain tap against the window, lost in thought.
arms and legs	0.3369926	0.6051687	alphabetical	Sentence (alphabetical)	+ Sandra broke her arms and legs because she got into a bike accident.	When he gets upset he crosses his arms and legs in a very tense manner.
arms and legs	0.3369926	0.6051687	alphabetical	Sentence (nonalphabetical)	+ Sandra broke her legs and arms because she got into a bike accident.	When he gets upset he crosses his arms and legs in a very tense manner.
arms and legs	0.3369926	0.6051687	nonalphabetical	Sentence (alphabetical)	+ Sandra broke her arms and legs because she got into a bike accident.	When he gets upset he crosses his legs and arms in a very tense manner.
arms and legs	0.3369926	0.6051687	nonalphabetical	Sentence (nonalphabetical)	+ Sandra broke her legs and arms because she got into a bike accident.	When he gets upset he crosses his legs and arms in a very tense manner.
arms and legs	0.3369926	0.6051687	unrelated	Sentence (alphabetical)	+ Sandra broke her arms and legs because she got into a bike accident.	The sun dipped below the horizon, painting the sky in shades of orange and pink.
arms and legs	0.3369926	0.6051687	unrelated	Sentence (nonalphabetical)	+ Sandra broke her legs and arms because she got into a bike accident.	The sun dipped below the horizon, painting the sky in shades of orange and pink.
arts and crafts	0.4952497	0.6080374	alphabetical	Sentence (alphabetical)	+ Lilly enjoys doing arts and crafts to relax when she is stressed.	Arts and crafts are a wonderful way to express creativity through handmade projects.
arts and crafts	0.4952497	0.6080374	alphabetical	Sentence (nonalphabetical)	+ Lilly enjoys doing crafts and arts to relax when she is stressed.	Arts and crafts are a wonderful way to express creativity through handmade projects.
arts and crafts	0.4952497	0.6080374	nonalphabetical	Sentence (alphabetical)	+ Lilly enjoys doing arts and crafts to relax when she is stressed.	Crafts and arts are a wonderful way to express creativity through handmade projects.
arts and crafts	0.4952497	0.6080374	nonalphabetical	Sentence (nonalphabetical)	+ Lilly enjoys doing crafts and arts to relax when she is stressed.	Crafts and arts are a wonderful way to express creativity through handmade projects.
arts and crafts	0.4952497	0.6080374	unrelated	Sentence (alphabetical)	+ Lilly enjoys doing arts and crafts to relax when she is stressed.	She poured herself a steaming cup of coffee, savoring the aroma as it filled the kitchen.
arts and crafts	0.4952497	0.6080374	unrelated	Sentence (nonalphabetical)	+ Lilly enjoys doing crafts and arts to relax when she is stressed.	She poured herself a steaming cup of coffee, savoring the aroma as it filled the kitchen.
goods and services	0.4925981	0.6638593	alphabetical	Sentence (alphabetical)	+ They would not trade goods and services even for a large sum of money.	The store offers a wide variety of goods and services to meet customer needs.
goods and services	0.4925981	0.6638593	alphabetical	Sentence (nonalphabetical)	+ They would not trade services and goods even for a large sum of money.	The store offers a wide variety of goods and services to meet customer needs.
goods and services	0.4925981	0.6638593	nonalphabetical	Sentence (alphabetical)	+ They would not trade goods and services even for a large sum of money.	The store offers a wide variety of services and goods to meet customer needs.
goods and services	0.4925981	0.6638593	nonalphabetical	Sentence (nonalphabetical)	+ They would not trade services and goods even for a large sum of money.	The store offers a wide variety of services and goods to meet customer needs.
goods and services	0.4925981	0.6638593	unrelated	Sentence (alphabetical)	+ They would not trade goods and services even for a large sum of money.	They toasted to friendship, clinking their glasses in celebration.
goods and services	0.4925981	0.6638593	unrelated	Sentence (nonalphabetical)	+ They would not trade services and goods even for a large sum of money.	They toasted to friendship, clinking their glasses in celebration.
feet and hands	-0.3822570	0.4219807	alphabetical	Sentence (alphabetical)	+ The child's feet and hands slowly grew very numb.	The dancer moved her feet and hands gracefully, commanding the stage.
feet and hands	-0.3822570	0.4219807	alphabetical	Sentence (nonalphabetical)	+ The child's hands and feet slowly grew very numb.	The dancer moved her feet and hands gracefully, commanding the stage.
feet and hands	-0.3822570	0.4219807	nonalphabetical	Sentence (alphabetical)	+ The child's feet and hands slowly grew very numb.	The dancer moved her hands and feet gracefully, commanding the stage.
feet and hands	-0.3822570	0.4219807	nonalphabetical	Sentence (nonalphabetical)	+ The child's hands and feet slowly grew very numb.	The dancer moved her hands and feet gracefully, commanding the stage.
feet and hands	-0.3822570	0.4219807	unrelated	Sentence (alphabetical)	+ The child's feet and hands slowly grew very numb.	The crisp autumn air was filled with the scent of pine and fallen leaves.
feet and hands	-0.3822570	0.4219807	unrelated	Sentence (nonalphabetical)	+ The child's hands and feet slowly grew very numb.	The crisp autumn air was filled with the scent of pine and fallen leaves.
gas and oil	-0.4145522	0.4149414	alphabetical	Sentence (alphabetical)	+ Sam didn't know the difference between gas and oil so she ruined her car.	The economy in this region is heavily dependent on gas and oil production.

gas and oil	-0.4145522	0.4149414	alphabetical	Sentence (nonalphabetical)	+ Sam didn't know the difference between oil and gas so she ruined her car.	The economy in this region is heavily dependent on gas and oil production.
gas and oil	-0.4145522	0.4149414	nonalphabetical	Sentence (alphabetical)	+ Sam didn't know the difference between gas and oil so she ruined her car.	The economy in this region is heavily dependent on oil and gas production.
gas and oil	-0.4145522	0.4149414	nonalphabetical	Sentence (nonalphabetical)	+ Sam didn't know the difference between oil and gas so she ruined her car.	The economy in this region is heavily dependent on oil and gas production.
gas and oil	-0.4145522	0.4149414	unrelated	Sentence (alphabetical)	+ Sam didn't know the difference between gas and oil so she ruined her car.	He sat by the campfire, warming his hands as the stars sparkled above.
gas and oil	-0.4145522	0.4149414	unrelated	Sentence (nonalphabetical)	+ Sam didn't know the difference between oil and gas so she ruined her car.	He sat by the campfire, warming his hands as the stars sparkled above.
death and life	-0.4380721	0.1047131	alphabetical	Sentence (alphabetical)	+ It is hard to tell the difference between death and life when you are in purgatory.	In many cultures, death and life are seen as intertwined parts of a greater cycle.
death and life	-0.4380721	0.1047131	alphabetical	Sentence (nonalphabetical)	+ It is hard to tell the difference between life and death when you are in purgatory.	In many cultures, death and life are seen as intertwined parts of a greater cycle.
death and life	-0.4380721	0.1047131	nonalphabetical	Sentence (alphabetical)	+ It is hard to tell the difference between death and life when you are in purgatory.	In many cultures, life and death are seen as intertwined parts of a greater cycle.
death and life	-0.4380721	0.1047131	nonalphabetical	Sentence (nonalphabetical)	+ It is hard to tell the difference between life and death when you are in purgatory.	In many cultures, life and death are seen as intertwined parts of a greater cycle.
death and life	-0.4380721	0.1047131	unrelated	Sentence (alphabetical)	+ It is hard to tell the difference between death and life when you are in purgatory.	The child's laughter echoed through the park as he chased after a butterfly.
death and life	-0.4380721	0.1047131	unrelated	Sentence (nonalphabetical)	+ It is hard to tell the difference between life and death when you are in purgatory.	The child's laughter echoed through the park as he chased after a butterfly.
boys and girls	0.3825196	0.6258780	alphabetical	Sentence (alphabetical)	+ The teacher separated the boys and girls into two small groups.	Boys and girls eagerly gathered around the storyteller for an afternoon of tales.
boys and girls	0.3825196	0.6258780	alphabetical	Sentence (nonalphabetical)	+ The teacher separated the girls and boys into two small groups.	Boys and girls eagerly gathered around the storyteller for an afternoon of tales.
boys and girls	0.3825196	0.6258780	nonalphabetical	Sentence (alphabetical)	+ The teacher separated the boys and girls into two small groups.	Girls and boys eagerly gathered around the storyteller for an afternoon of tales.
boys and girls	0.3825196	0.6258780	nonalphabetical	Sentence (nonalphabetical)	+ The teacher separated the girls and boys into two small groups.	Girls and boys eagerly gathered around the storyteller for an afternoon of tales.
boys and girls	0.3825196	0.6258780	unrelated	Sentence (alphabetical)	+ The teacher separated the boys and girls into two small groups.	The mountain trail was steep, but the view from the top made every step worth it.
boys and girls	0.3825196	0.6258780	unrelated	Sentence (nonalphabetical)	+ The teacher separated the girls and boys into two small groups.	The mountain trail was steep, but the view from the top made every step worth it.
cause and effect	0.4893921	0.7803896	alphabetical	Sentence (alphabetical)	+ Ryan was uncertain about the cause and effect of inflation, so he did some research.	The gathering was filled with laughter from brothers and sisters catching up after a long time apart.
cause and effect	0.4893921	0.7803896	alphabetical	Sentence (nonalphabetical)	+ Ryan was uncertain about the effect and cause of inflation, so he did some research.	The gathering was filled with laughter from brothers and sisters catching up after a long time apart.
cause and effect	0.4893921	0.7803896	nonalphabetical	Sentence (alphabetical)	+ Ryan was uncertain about the cause and effect of inflation, so he did some research.	The gathering was filled with laughter from sisters and brothers catching up after a long time apart.
cause and effect	0.4893921	0.7803896	nonalphabetical	Sentence (nonalphabetical)	+ Ryan was uncertain about the effect and cause of inflation, so he did some research.	The gathering was filled with laughter from sisters and brothers catching up after a long time apart.
cause and effect	0.4893921	0.7803896	unrelated	Sentence (alphabetical)	+ Ryan was uncertain about the cause and effect of inflation, so he did some research.	She carefully wrapped the gift, tying a red ribbon into a perfect bow.
cause and effect	0.4893921	0.7803896	unrelated	Sentence (nonalphabetical)	+ Ryan was uncertain about the effect and cause of inflation, so he did some research.	She carefully wrapped the gift, tying a red ribbon into a perfect bow.
pepper and salt	-0.4392495	0.2688839	alphabetical	Sentence (alphabetical)	+ The food is in need of pepper and salt because it's rather bland.	She added just a pinch of pepper and salt to bring out the flavors of the dish.
pepper and salt	-0.4392495	0.2688839	alphabetical	Sentence (nonalphabetical)	+ The food is in need of salt and pepper because it's rather bland.	She added just a pinch of pepper and salt to bring out the flavors of the dish.
pepper and salt	-0.4392495	0.2688839	nonalphabetical	Sentence (alphabetical)	+ The food is in need of pepper and salt because it's rather bland.	She added just a pinch of salt and pepper to bring out the flavors of the dish.
pepper and salt	-0.4392495	0.2688839	nonalphabetical	Sentence (nonalphabetical)	+ The food is in need of salt and pepper because it's rather bland.	She added just a pinch of salt and pepper to bring out the flavors of the dish.
pepper and salt	-0.4392495	0.2688839	unrelated	Sentence (alphabetical)	+ The food is in need of pepper and salt because it's rather bland.	The dog barked at the mailman every day, as if it were his sworn duty.
pepper and salt	-0.4392495	0.2688839	unrelated	Sentence (nonalphabetical)	+ The food is in need of salt and pepper because it's rather bland.	The dog barked at the mailman every day, as if it were his sworn duty.
female and male	-0.4263521	0.3493327	alphabetical	Sentence (alphabetical)	+ The dog breeder said the female and male puppies are coming today.	The study found no significant differences in learning styles between female and male students.
female and male	-0.4263521	0.3493327	alphabetical	Sentence (nonalphabetical)	+ The dog breeder said the male and female puppies were coming today.	The study found no significant differences in learning styles between female and male students.

female and male	-0.4263521	0.3493327	nonalphabetical	Sentence (alphabetical)	+ The dog breeder said the female and male puppies are coming today.	The study found no significant differences in learning styles between male and female students.
female and male	-0.4263521	0.3493327	nonalphabetical	Sentence (nonalphabetical)	+ The dog breeder said the male and female puppies were coming today.	The study found no significant differences in learning styles between male and female students.
female and male	-0.4263521	0.3493327	unrelated	Sentence (alphabetical)	+ The dog breeder said the female and male puppies are coming today.	She wrote down her goals in a new journal, determined to make this year different.
female and male	-0.4263521	0.3493327	unrelated	Sentence (nonalphabetical)	+ The dog breeder said the male and female puppies were coming today.	She wrote down her goals in a new journal, determined to make this year different.
brothers and sisters	0.4142403	0.6388390	alphabetical	Sentence (alphabetical)	+ Andrew shared with his brothers and sisters, so he was excited to have a roommate.	I always love seeing my brothers and sisters when I go home for the holidays.
brothers and sisters	0.4142403	0.6388390	alphabetical	Sentence (nonalphabetical)	+ Andrew shared with his sisters and brothers, so he was excited to have a roommate.	I always love seeing my brothers and sisters when I go home for the holidays.
brothers and sisters	0.4142403	0.6388390	nonalphabetical	Sentence (alphabetical)	+ Andrew shared with his brothers and sisters, so he was excited to have a roommate.	I always love seeing my sisters and brothers when I go home for the holidays.
brothers and sisters	0.4142403	0.6388390	nonalphabetical	Sentence (nonalphabetical)	+ Andrew shared with his sisters and brothers, so he was excited to have a roommate.	I always love seeing my sisters and brothers when I go home for the holidays.
brothers and sisters	0.4142403	0.6388390	unrelated	Sentence (alphabetical)	+ Andrew shared with his brothers and sisters, so he was excited to have a roommate.	They exchanged a knowing glance, each understanding the other's unspoken thoughts.
brothers and sisters	0.4142403	0.6388390	unrelated	Sentence (nonalphabetical)	+ Andrew shared with his sisters and brothers, so he was excited to have a roommate.	They exchanged a knowing glance, each understanding the other's unspoken thoughts.
fall and rise	-0.4700519	0.4320348	alphabetical	Sentence (alphabetical)	+ I've gotten particularly ill due to the fall and rise of the big waves.	The documentary charts the fall and rise of a once-beloved artist.
fall and rise	-0.4700519	0.4320348	alphabetical	Sentence (nonalphabetical)	+ I've gotten particularly ill due to the rise and fall of the big waves.	The documentary charts the fall and rise of a once-beloved artist.
fall and rise	-0.4700519	0.4320348	nonalphabetical	Sentence (alphabetical)	+ I've gotten particularly ill due to the fall and rise of the big waves.	The documentary charts the rise and fall of a once-beloved artist.
fall and rise	-0.4700519	0.4320348	nonalphabetical	Sentence (nonalphabetical)	+ I've gotten particularly ill due to the rise and fall of the big waves.	The documentary charts the rise and fall of a once-beloved artist.
fall and rise	-0.4700519	0.4320348	unrelated	Sentence (alphabetical)	+ I've gotten particularly ill due to the fall and rise of the big waves.	She gazed out at the ocean, mesmerized by the endless waves crashing against the shore.
fall and rise	-0.4700519	0.4320348	unrelated	Sentence (nonalphabetical)	+ I've gotten particularly ill due to the rise and fall of the big waves.	She gazed out at the ocean, mesmerized by the endless waves crashing against the shore.
feelings and thoughts	-0.3486352	0.4183383	alphabetical	Sentence (alphabetical)	+ When Pat gets frustrated, her feelings and thoughts get muddled quite quickly.	Poetry often tries to capture the subtle interplay of feelings and thoughts.
feelings and thoughts	-0.3486352	0.4183383	alphabetical	Sentence (nonalphabetical)	+ When Pat gets frustrated, her thoughts and feelings get muddled quite quickly.	Poetry often tries to capture the subtle interplay of feelings and thoughts.
feelings and thoughts	-0.3486352	0.4183383	nonalphabetical	Sentence (alphabetical)	+ When Pat gets frustrated, her feelings and thoughts get muddled quite quickly.	Poetry often tries to capture the subtle interplay of thoughts and feelings.
feelings and thoughts	-0.3486352	0.4183383	nonalphabetical	Sentence (nonalphabetical)	+ When Pat gets frustrated, her thoughts and feelings get muddled quite quickly.	Poetry often tries to capture the subtle interplay of thoughts and feelings.
feelings and thoughts	-0.3486352	0.4183383	unrelated	Sentence (alphabetical)	+ When Pat gets frustrated, her feelings and thoughts get muddled quite quickly.	He flipped through the album, each photograph bringing back a flood of memories.
feelings and thoughts	-0.3486352	0.4183383	unrelated	Sentence (nonalphabetical)	+ When Pat gets frustrated, her thoughts and feelings get muddled quite quickly.	He flipped through the album, each photograph bringing back a flood of memories.
days and nights	0.4144469	0.6530894	alphabetical	Sentence (alphabetical)	+ Finn spent many days and nights working on writing his novel.	The desert's harshness is evident in the extreme days and nights.
days and nights	0.4144469	0.6530894	alphabetical	Sentence (nonalphabetical)	+ Finn spent many nights and days working on writing his novel.	The desert's harshness is evident in the extreme days and nights.
days and nights	0.4144469	0.6530894	nonalphabetical	Sentence (alphabetical)	+ Finn spent many days and nights working on writing his novel.	The desert's harshness is evident in the extreme nights and days.
days and nights	0.4144469	0.6530894	nonalphabetical	Sentence (nonalphabetical)	+ Finn spent many nights and days working on writing his novel.	The desert's harshness is evident in the extreme nights and days.
days and nights	0.4144469	0.6530894	unrelated	Sentence (alphabetical)	+ Finn spent many days and nights working on writing his novel.	The crowded marketplace buzzed with the sounds of bargaining and laughter.
days and nights	0.4144469	0.6530894	unrelated	Sentence (nonalphabetical)	+ Finn spent many nights and days working on writing his novel.	The crowded marketplace buzzed with the sounds of bargaining and laughter.