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## Frequency effects in the auditory grammatical decision task

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Abstract:

We investigated effects of phrase-frequency and the frequency of content words in two auditory grammatical decision experiments testing grammatically correct 4-word phrases intermixed with ungrammatical 4-word sequences. A significant phrase-frequency effect was found in Experiment 1 while controlling for syntactic structure (the sequence of parts-of-speech) and word-frequency. No effect of word-frequency was found in Experiment 2 when controlling for phrase-frequency and syntactic structure. A third experiment measured the cloze probability of the final words of the grammatically correct phrases tested in Experiments 1 and 2. Although entering cloze probability as a covariate rendered the effect of phrase-frequency non-significant, a re-analysis of a subset of phrases matched for cloze probability revealed a significant effect of phrase-frequency, while the effect of word-frequency remained non-significant.

(122 words)

Key words: Auditory grammatical decision; Phrase-frequency; Word-frequency; Cloze probability

Frequency effects are perhaps the most well-established effects in the field of psycholinguistics and have been observed for units of different grain size. There are numerous demonstrations that language users are sensitive to the frequency of letters (e.g., New & Grainger, 2011), syllables (e.g., Perea & Carreiras, 1998), words (e.g., Morton, 1969; see Monsell, 1991, for a review), morphemes (e.g., Giraudo & Grainger, 2000; Janssen et al., 2008; Sereno & Jongman, 1997) and two-word combinations (e.g., Reali & Christiansen, 2007; Sosa & McFarlane, 2002). However, to date very few studies have investigated frequency effects for multi-word phrases composed of more than two words, and none so far have done so for spoken language comprehension. The present study was designed to fill this gap.

Whether or not language processing is affected by the frequency with which multi-word phrases appear in a language has strong theoretical implications since it provides a strong test of two radically opposed views of how adult humans understand language. The traditional view (Pinker, 1998; Pinker & Ullman, 2002) assumes a mental lexicon which is separated from the grammar. Linguistic elements such as words would be stored in long-term memory and the grammar would represent a set of formal rules describing how to combine words to generate grammatically correct phrases. Under this view, only linguistic elements that cannot be computed by the means of rules would be stored in memory and be sensitive to their frequency of occurrence. As a result, this view predicts an influence of the frequency of the words that compose a phrase, but no effect of the frequency of the entire phrase. The opposite view often referred to as “emergentist” theories, including usage-based approaches to grammar (Bybee, 1998; Langacker, 1988; Tomasello, 2003), connectionist models of learning and processing (Christiansen & Chater, 1999; Elman, 2009; MacWhinney, 1998; Rumelhart & McClelland, 1986; Seidenberg, 1994) and exemplar models of linguistic storage

(Gahl & Yu, 2006; Pierrehumbert, 2001), rejects the idea of a system composed of words and rules. According to this proposal the lexicon and the grammar cannot be separated, and the grammar would emerge from the repeated exposure of complex linguistic patterns. Language users should therefore be sensitive to the frequency of occurrence of units larger than words. This view therefore predicts an effect of phrase-frequency with no influence of the frequency of the words that compose the phrases, since multi-word phrases are assumed to be accessed directly in memory.

There are only a handful of studies that have attempted to distinguish between these two opposing views by examining the processing of multi-word phrases. In a seminal study, Arnon and Snider (2010) asked participants to decide whether a visually presented sequence of four words was a possible phrase in English or not (i.e., a grammatical decision task). Phrases were either of low (e.g., Don't have to wait) or high-frequency (e.g., Don't have to worry), and the phrases in the two conditions differed only on the last word in the sequence that was matched for word-frequency and syntactic category. The results from two experiments revealed faster grammatical decision responses to high-frequency phrases than to low-frequency phrases. Moreover, this phrase-frequency effect was observed across the entire range of phrase frequencies (low, mid, high). Further evidence in favor of a phrase-frequency effect with visually presented multi-word phrases was obtained in an eye-tracking study by Siyanova-Chanturia et al. (2011). They examined processing of 3-word binomial phrases such as *bride and groom* and their reversed forms *groom and bride*, that differ in phrase-frequency<sup>1</sup> but are matched in terms of word-frequency and syntactic structure. They reported that both native and proficient non-native English speakers were sensitive to the frequency of the multi-

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<sup>1</sup> Siyanova-Chanturia et al. used the term “phrasal frequency”. Here we follow Arnon and Snider in using the term “phrase-frequency” in analogy with the widely used term “word-frequency” in the single word processing literature.

word sequences, with phrase-frequency facilitating reading. Moreover, Siyanova-Chanturia et al. also reported that the individual frequencies of the two content words (i.e., *bride*, *groom*, in the above example) were not significant predictors of reading speed. Finally, Armando et al. (2023) replicated the grammatical decision findings of Arnon and Snider (2010) while calculating phrase frequency using counts extracted from the very large Google Ngram database (the creation of a database of more reliable multi-word frequencies was the main goal of that study).

Phrase-frequency effects have also been found in tasks involving spoken language production. Janssen and Barber (2012) asked participants to produce French phrases composed of a determiner followed by a noun followed by an adjective with a picture serving as the eliciting stimulus (e.g., *une maison bleu* elicited by a picture of a blue house). They found that naming latencies were significantly faster for high-frequency phrases relative to low-frequency phrases. However, and in line with the results of Siyanova-Chanturia et al. (2011), the naming latencies were not influenced by the frequency of the component words. The results of Janssen and Barber were replicated in a study by Jeong et al. (2021), this time with electrophysiological as well as behavioral measures of language production and recombining the same words to form high- and low-frequency two-word (adjective-noun) sequences. Naming latencies were again found to be faster for the high-frequency phrases, and the electrophysiological data suggested that the locus of this phrase-frequency effect was during the encoding of linguistic information from a pictorial representation.

The main aim of the present study was to establish, for the first time, a phrase-frequency effect in spoken language comprehension. As noted above, prior research has found phrase-frequency effects in written language comprehension and spoken language production,

so the present study fills one of the two remaining gaps (the other being written language production). Concerning effects of phrase-frequency in language comprehension, one crucial difference between the auditory and the visual modalities is that in spoken phrases, words occur one after the other, which is not the case in a reading context where all the words in the phrases are presented simultaneously.

Since the work of Arnon and Snider (2010), phrase-frequency effects have been taken as evidence against a “words and rules” approach to language comprehension (e.g., Pinker, 1998; Pinker & Ullman, 2002) and evidence in favor of so-called “emergentist” approaches. As discussed above, according to the latter approach, information concerning groups of words, and not just single words, is stored in long-term memory possibly in the form of chunks (i.e., a single representation for a group of frequently co-occurring words: Bybee, 1998; Langacker, 1988; Tomasello, 2003) or in the form of connection weights or probabilistic constraints determined by word co-occurrences (e.g., Christiansen & Chater, 1999; Elman, 2009; McDonald & Shillcock, 2003; MacWhinney, 1998; Rumelhart & McClelland, 1986). However, with respect to language comprehension, it is possible that written language encourages the development of such multi-word representations given the simultaneous availability of information concerning several words (Snell & Grainger, 2019). Finding a phrase-frequency effect in the auditory modality would therefore provide greater support for emergentist approaches to language comprehension in general.

Finally, and at a more methodological level, it should be noted that three of the studies that have reported effects of phrase-frequency have done so using one specific syntactic structure (binomial phrases in Siyanova-Chanturia et al., 2011; determiner + noun + adjective

phrases in Janssen & Barber, 2012; adjective-noun phrases in Jeong et al., 2021), and thus it is unclear whether phrase-frequency effects could be found when participants have to process a greater variety of syntactic structures. Arnon and Snider (2010) did use a greater variety of syntactic structures than in the three above-cited studies. However, in the Arnon and Snider study the phrases tested in the two frequency conditions always differed on the final word, and thus expectations concerning the final word could at least partly explain the phrase-frequency effect they observed. Furthermore, Arnon and Snider tested for phrase-frequency effects in the visual modality while measuring phrase-frequency using a corpus of spoken language (see Armando et al., 2023, for a replication using a corpus of written language). In the present study we tested phrase-frequency effects in the auditory modality using a corpus of spoken language (film subtitles) to measure phrase-frequency and using a variety of syntactic structures with phrases that were formed of different words at all positions.

In sum, the goal of the present study was to examine the contribution of phrase-frequency and word-frequency during spoken sentence processing. To do so, two experiments were conducted using four-word phrases. In Experiment 1 we tested phrases that differed in frequency but that were matched on the frequency of the content words, while in Experiment 2 we tested phrases that differed in terms of the frequency of content words but that were matched on phrase-frequency. Following Arnon and Snider (2010), we used a speeded grammatical decision task with word sequences that could either form a grammatically correct phrase or an ungrammatical sequence. This task can be considered as the sentence-level equivalent of the lexical decision task that has been widely used to study word-frequency effects. Furthermore, the utility of this task for the study of both written and spoken language comprehension has been demonstrated in numerous prior studies (e.g., Dufour et al., 2022; Mirault et al., 2018; Mirault & Grainger, 2020).

## Experiment 1

In Experiment 1 we tested phrase-frequency effect using four-word phrases matched on the word-frequency. If the phrase-frequency effect previously found with written sentences generalizes to spoken language, then high-frequency phrases should be responded to more quickly than low-frequency phrases. High- and low-frequency phrases with various syllabic and syntactic structures (but matched on these variables) were tested, and across the two frequency conditions phrases were made up of different words at all positions.

### Methods

Participants: 60 participants were recruited on-line for the experiment. They reported to be native speakers of French and their reported age was between 18 and 62 years. Note that only 2 participants were over 60 years old. Exactly the same pattern of results was observed with and without these participants. So we decided to retain their data in the analysis. Prior to the beginning of the experiment, participants provided informed consent and they were informed that the data would be collected anonymously. Ethics approval for this and the following experiments was obtained from the *Comité de Protection des Personnes* SUD-EST IV (No. 17/051).

Materials: We selected 60 grammatical phrases made up of four words from the French corpus of film subtitles of 316 million words (New et al., 2007). Half of them were low-frequency phrases and the other half were high-frequency phrases. High- and low-frequency phrases were matched on grammatical structures. For example, the high-frequency phrase

*vous avez ma parole* “you have my word” and the low-frequency phrase *je veux ton bonheur* “I want your happiness” both consist in a personal pronoun, a verb, a possessive adjective and a noun. The phrases with their grammatical structure are given in Appendix 1. Overall, 23 different syntactic structures were used, and the number of phrases within each syntactic structure varied between 1 and 3 in the two frequency conditions. The high- and low-frequency phrases were also matched on words frequencies. The main characteristics of the phrases are given in Table 1. For the purpose of the grammatical decision task, 60 grammatically incorrect phrases were also constructed. To do so, we selected 60 grammatical phrases of four words not previously used, and we replaced the last word by another word which is grammatically incorrect. For example, the last word *match* which is a noun in the phrase *la balle de match* “the match point” was replaced by the adverb *tranquillement* leading thus to “la balle de tranquillement” which is grammatically incorrect since in French the preposition *de* cannot be followed by an adverb. Note that the last word was changed to force participants to process the entire phrase prior to giving their response. The 120 word sequences (i.e., 60 grammatical and 60 ungrammatical) were recorded using “text-to-speech” for French and with the female voice called “Denise” and digitized at a sampling rate of 44100 Hz.

Procedure: The experiment was programmed using Labvanced software (Finger et al., 2017). Participants were instructed to put on their headphones and adjust the volume to a comfortable sound level. A trial began with a centrally aligned fixation cross for a duration of 500 ms, followed by the auditory phrase. For each word sequence, participants were asked to make a grammatical decision as quickly and accurately as possible by pressing the “right arrow” for grammatically correct sentences and the “left arrow” for ungrammatical sequences. After each response, feed-back was provided for a duration of 500 ms in the form of a green

circle for a correct response and a red cross for an incorrect response was presented. The order of presentation of word sequences was randomized for each participant. Participants were tested on only one experimental list, and began the experiment with 6 practice trials.

## Results and Discussion

RTs to the critical grammatical sequences (available at <https://osf.io/hn2x8/>; Open Science Framework; Foster & Deardorff, 2017) were analyzed using linear mixed effects models with participants and items as crossed random factors, using R software and the lme4 package (Baayen et al., 2008). The RT analysis was performed on correct responses, thus removing 114 (3.17%) data points out of 3600. RTs greater than 4,000 ms (0.29%) were considered as outliers and were also excluded from the analysis. For the model to meet the assumptions of normally-distributed residuals and homogeneity of variance, a log transformation was applied to the RTs (Baayen & Milin, 2010) prior to running the model. The model was run on 3476 data points. We tested a model with the variable Phrase-frequency (low, high) entered as fixed effect. Given that there were slight differences in overall phrase duration, this factor was entered as a covariate. The reference was the high-frequency condition. The model failed to converge when random participant and item slopes were included (see Barr et al., 2013). Therefore, the final model only included random intercepts for participants and items. Response accuracy was analyzed using a mixed-effects logit model (Jaeger, 2008) following the same procedure as for RTs.

The effect of Phrase-frequency was significant in RTs ( $b = 0.0502$ ,  $SE = 0.0111$ ,  $t = 4.53$ ,  $p < .001$ ). Participants responded 72 ms faster in the high-frequency (Mean = 1224 ms) than in the low-frequency (Mean = 1296 ms) condition. The effect of Phrase-frequency was also significant in the analysis of error rates ( $b = -1.2159$ ,  $SE = 0.3071$ ,  $z = -3.96$ ,  $p < .001$ ).

Participants made fewer errors to high-frequency (Mean = 1%) than to low-frequency phrases (Mean = 5%).

Using the same task as Arnon and Snider (2010), but this time in the auditory modality, Experiment 1 replicated the phrase-frequency effect previously observed with written four-word phrases. Participants took longer to decide that an auditorily presented four-word phrase was grammatically correct when they were of low-frequency compared with high-frequency phrases. The phrase-frequency effect was obtained here with phrases of various syntactic structures and composed of different words that were matched in word-frequency across positions. Furthermore, the measure of phrase-frequency (subtitle frequency) was matched to the modality of presentation of the phrases (spoken).

## **Experiment 2**

Since during reading the individual words that make up a phrase are available at the same time, this specific situation could diminish the weight of individual words, thus masking the influence of word-frequency as reported in prior research (Siyanova-Chanturia et al., 2011). The auditory modality, in contrast, favors word-by-word processing, and it is therefore important to know whether word-frequency can play a role in the processing of spoken phrases when phrase-frequency is controlled for. In Experiment 2, we therefore tested for word-frequency effects with four-word phrases matched on phrase-frequency. Note that due to the very high-frequency of closed-class words (i.e., determiners, pronouns, etc.), and the fact that single word-frequency manipulations almost always concern content words, here

word-frequency was only manipulated on content words. The content words always occupied the second and the fourth positions in the phrases. This led to a lower number of different syntactic structures than in Experiment 1, but given the focus on individual word-frequency effects rather than phrase-frequency effects we considered this to not be problematic.

## **Methods**

Participants: 60 participants were recruited on-line for the experiment. They reported to be native speakers of French and their reported age was between 18 and 62 years. Note that only 4 participants were over 60 years old. Exactly the same pattern of results was observed with and without these participants. So we decided to retain their data in the analysis. Prior to the beginning of the experiment, participants provided informed consent and they were informed that the data would be collected anonymously. None had taken part in Experiment 1.

Materials: As in Experiment 1, we selected 60 grammatical phrases made up of four words from the French corpus of film subtitles (New et al., 2007). Due to the difficulty to select two groups of phrases matched on their global frequency, but with frequency differences on all of the four words, we decided to keep constant the first and third word across the two frequency conditions. As a result word-frequency was only manipulated on the second and fourth words, which were content words, either nouns or verbs. For half of the 60 phrases the second and fourth words were of high-frequency (e.g., *un numéro de téléphone* “a phone number”), and for the other half the second and fourth words were of low-frequency (e.g., *un terrain de golf* “a golf course”). The phrases with their grammatical structure are given in Appendix 2. Overall, 6 different syntactic structures were used, and in the two frequency conditions there were two predominant syntactic structures comprising respectively 7 (23%) and 15 (50%) phrases. For the four other structures, the number of phrases varied between 1 and 3 in the

two frequency conditions. The main characteristics of the phrases are summarized in Table 2. 60 ungrammatical sequences were added to the stimulus list and were constructed in the same way as in Experiment 1. The same procedure as Experiment 1 was used for the recording of the 120 word sequences (60 grammatical, 60 ungrammatical).

Procedure: This was the same as in Experiment 1.

## **Results and Discussion**

RTs to the critical grammatical sequences (available at <https://osf.io/hn2x8/>) were analyzed using linear mixed effects models following the same procedure as in Experiment 1. The RT analysis was performed on correct responses, thus removing 130 (3.61%) data points out of 3600. RTs smaller than 500 ms and those greater than 4,000 ms were considered as outliers (0.72%) and were also excluded from the analysis. For the model to meet the assumptions of normally-distributed residuals and homogeneity of variance, a log transformation was applied to the RTs (Baayen & Milin, 2010) prior to running the model. The model was run on 3445 data points. We tested a model with the variable Word-frequency (low, high) entered as fixed effect. As in Experiment 1, the factor phrase duration was entered as covariate. The reference was the high-frequency condition. The model failed to converge when random participant and item slopes were included (see Barr et al., 2013). Therefore, the final model only included random intercepts for participants and items.

The effect of Word-frequency was not significant ( $b = 0.0081$ ,  $SE = 0.0115$ ,  $t = 0.70$ ,  $p > .20$ ; RTs (high-frequency) = 1306 ms; RTs (low-frequency) = 1318 ms).

Response accuracy was analyzed using a mixed-effects logit model (Jaeger, 2008) following the same procedure as for RTs. The effect of Word-frequency was again not significant ( $b = -0.1897$ ,  $SE = 0.2701$ ,  $z = -0.70$ ,  $p > .20$ ; Error rate (High-frequency) = 3%; Error rate (Low-frequency) = 4%).

The failure to observe an influence of word-frequency during the processing of phrases is in line with the findings reported by Siyanova-Chanturia et al. (2011) for written language comprehension and Janssen and Barber (2012) for spoken language production. Taken together, these results suggest that comprehending and producing phrases is not influenced by individual word-frequency. However, it remains to be seen whether or not there are confounding factors at play here, one of which might be cloze probability. Experiment 3 was designed to examine this.

### **Experiment 3**

In Experiments 1 and 2 we replicated the phrase-frequency effect previously observed in written language comprehension (Arnon and Snider, 2010; Siyanova-Chanturia et al., 2011) and in spoken language production (Janssen & Barber, 2012; Jeong et al., 2021). In line with these prior studies, we failed to find an influence of individual word-frequency during the processing of multi-word phrases. However, there is one issue that remains to be addressed in the study of phrase-frequency effects during spoken language comprehension – that is the fact that phrase-frequency correlates highly with word predictability. This issue was already raised by Siyanova-Chanturia et al. (2011) who reported a strong correlation between

their completion test scores (e.g., complete the phrase “bride and ...”) and phrase-frequency. However, the effects of phrase-frequency remained significant when the completion test scores were entered as a covariate. Siyanova-Chanturia et al. did nevertheless note the difficulty in separating out effects of phrase-frequency from effects of predictability. We therefore decided to re-examine this issue using a classic measure of cloze probability. To do so we measured the cloze probability of the final words in our grammatically correct phrases. This corresponds to the proportion of participants that produced these words as the most appropriate completion of the preceding context, that is, the first three words of the sequence.

## **Method**

Participants: 84 participants were recruited on-line for the experiment. They reported to be native speakers of French and their reported age was between 18 and 74 years. Note that only 3 participants were over 60 years old. Exactly the same pattern of results was observed with and without these participants. So we decided to retain their data in the analysis. Prior to the beginning of the experiment, participants provided informed consent and they were informed that the data would be collected anonymously.

Materials: The grammatically correct phrases of Experiments 1 & 2 were reused. The first three words of each of the 120 phrases were recorded using “text-to-speech” for French and with the same voice as in Experiments 1 & 2.

Procedure: The experiment was programmed using Labvanced software (Finger et al., 2017). Participants listened to the first three words of the grammatically correct phrases and were

asked to type the first word that came to their mind as the most likely continuation of that word sequence.

## Results and Discussion

Cloze probability (available at <https://osf.io/hn2x8/>) was calculated using the algorithm developed by Mirault et al. (2021) and corresponds to the number of responses that match the final words in the original sentences divided by the number of participants. Note that the Mirault et al. algorithm includes inflected and derived forms of the target word, as well as minor spelling mistakes and typographical errors as correct matches to the target. The average cloze probability was 0.30 for the high-frequency phrases and 0.12 for the low-frequency phrases of Experiment 1 ( $t(58) = 2.95; p < .01$ ). It was 0.17 for the phrases composed of high-frequency words and 0.28 for the phrases composed of low-frequency words of Experiment 2 ( $t(58) = 2.14; p < .05$ ).

Given that the final words of high-frequency phrases are more predictable than the final words of low-frequency phrases, cloze probability rather than phrase-frequency could be responsible of the effect observed in Experiment 1. Also, the greater cloze probability of the final words for the phrases of Experiment 2 composed of low-frequency words could have neutralized the word-frequency effect. We thus reanalyzed the results of Experiments 1 and 2 with cloze probability entered as a covariate. The phrase-frequency effect of Experiment 1 was no longer significant, both in RTs ( $b = 0.1384, SE = 0.0809, t = 1.71, p = .11$ ) and errors ( $b = -0.4600, SE = 1.0530, z = -0.44, p > .20$ ). The word-frequency effect of Experiment 2 was again not significant (RT:  $b = -0.1202, SE = 0.0899, t = -1.34, p > .20$ ; Error:  $b = -0.1761, SE = 0.1515, z = -0.01, p > .20$ ).

We performed additional analyses by selecting for each experiment two subsets of phrases matched on cloze probability. The subsets included 15 phrases for each phrase-frequency condition in Experiment 1, and 20 phrases in each word-frequency condition in Experiment 2. The characteristics of these new sets of phrases are summarized in Table 3, and the cloze probabilities of each of these phrases are given in Appendix 3. Note that the diversity of syntactic structures in Experiment 1 was the same in the re-analysis of Experiment 1 with subsets of phrases composed of 13 different syntactic structures. Also, the two predominant grammatical structures in Experiment 2 were the same and in the same proportions in the subset analysis of Experiment 2, with 5 (25%) and 10 (50%) phrases per structure in each word-frequency condition. Given that there were slight differences in overall phrase duration (see Table 3), this factor was entered as a covariate in both the RT and error analyses. A significant effect of phrase-frequency was found in Experiment 1 ( $b = 0.0552$ ,  $SE = 0.0166$ ,  $t = 3.32$ ,  $p < .01$ ). Participants responded 74 ms faster in the high-frequency (Mean = 1217 ms) than in the low-frequency (Mean = 1291 ms) condition. The effect of phrase-frequency was also significant in the error analysis ( $b = -0.8171$ ,  $SE = 0.3934$ ,  $z = -2.08$ ,  $p < .05$ ). Participants made fewer errors to high-frequency (Mean = 2%) than to low-frequency phrases (Mean = 5%) condition. The effect of word-frequency was again not significant in Experiment 2, both in the analysis of RTs ( $b = 0.0201$ ,  $SE = 0.0142$ ,  $t = 1.41$ ,  $p = .17$ ; RTs (high-frequency) = 1305 ms; RTs (low-frequency) = 1324 ms) and Errors ( $b = -0.3319$ ,  $SE = 0.3006$ ,  $z = -1.10$ ,  $p > .20$ ; Error rate (High-frequency) = 3%; Error rate (Low-frequency) = 5%).

The results of the cloze-test and the re-analysis of Experiment 1 with cloze probability entered as a covariate suggested that phrase-frequency effects might be confounded with probabilistic constraints as measured by the cloze-test. However, a re-analysis of a subset of

phrases that were matched in cloze-probability did reveal a significant effect of phrase-frequency. One possibility, to be discussed in more detail below, is that probabilistic constraints do play a role in driving phrase-frequency effects, but that the cloze test is an imperfect measure of such constraints. As concerns the effects of word-frequency in Experiment 2, these remained non-significant when cloze probabilities were included as a covariate, and also in a re-analysis of a subset of phrases matched for cloze probability. This points to at most a minimal role for individual content word-frequency when making grammatical decisions to auditorily presented sequences of words. We suspect that this is due to the key role played by function words in the elaboration of syntactic structures that are used to make a grammatical decision (see Schmauder et al., 2000, for a review).

### **General Discussion**

Two auditory grammatical decision experiments examined effects of phrase-frequency and word-frequency in spoken language comprehension. Phrase-frequency was measured in terms of the number of occurrences of a given sequence of four words in a corpus of spoken language. The word-frequency manipulation only concerned the content words in the sequence (i.e., two out of four words). In Experiment 1, a facilitatory effect of phrase-frequency was found while controlling for word-frequency and syntactic structure (i.e., the sequence of parts-of-speech). In Experiment 2, no effect of word-frequency was found while controlling for phrase-frequency. As a test of the potential mechanisms driving the phrase-frequency effect observed in Experiment 1 and the absence of a word-frequency effect in Experiment 2, in Experiment 3 we measured the cloze probability of the final words in the sequences tested in Experiments 1 and 2. We found that word-frequency effects remained

non-significant even if the sequences with high-frequency words did have lower cloze probabilities. Crucially, although phrase-frequency effects were no longer significant when cloze probability was entered as a covariate, they were significant in a re-analysis of a subset of phrases matched on cloze probability.

As noted in the Introduction, the present examination of word-frequency and phrase-frequency effects in spoken language comprehension provides a strong test of two opposing accounts of how adult humans comprehend language. Contrary to the “word and rules” account, we found significant phrase frequency effects in the absence of word frequency effects. These findings are clearly in support of “emergentist” accounts of language comprehension that predicted a dominant effect of phrase frequency, with word frequency only providing support during the construction of multi-word sequences. This interpretation of the present findings leads to the interesting prediction that the interplay between word-frequency and phrase-frequency effects should evolve during language acquisition, with word frequency effects playing a stronger role in young children.

Phrase-frequency effects have now been reported in several studies investigating written language processing (Armando et al., 2023; Arnon & Snider, 2010; Siyanova-Chanturia et al., 2011) and spoken language production (Janssen & Barber, 2012; Jeong et al., 2021). The present study was designed to provide additional information with respect to phrase-frequency effects, this time in spoken language comprehension. Importantly, we tested for phrase-frequency effects using a wide variety of syntactic structures and content words, which we believe to be more representative of everyday spoken language experience. Moreover, in line with our auditory testing procedure we measured phrase-frequency using a

corpus of spoken language (film subtitles). We found significant phrase-frequency effects in the grammatical decision task in Experiment 1. Importantly, as noted above, these remained significant in a re-analysis of a subset of phrases that were matched on the cloze probabilities of the final words in the phrase (collected in Experiment 3). These findings partly overlap with those reported by Siyanova-Chanturia et al. (2011), and we concur with these authors that it might actually be impossible to disentangle a “predictability” account from a “chunking” account of phrase-frequency effects due to the high correlation between these factors. This is clearly an important avenue for future research. Although “chunking” (e.g., Aron & Snider, 2010) or “lexicalization” (a term used to describe the representation of idiomatic expressions: e.g., Conklin & Schmitt, 2012; Swinney & Cutler, 1979) might be a viable mechanism for processing the frequency of occurrence of relatively short word sequences, we suspect that inter-word probabilistic constraints rather than chunk frequency provide a more general mechanism for explaining phrase-frequency effects.

Evidence for a role for such probabilistic constraints in text reading was provided by Snell and Theeuwes (2020). One particularly interesting aspect of their study was the finding that the frequency of a sequence of word lengths in a corpus (e.g., 2-letter, then 5-letter, then 3-letter), independently of word identities, affected readers eye-movements even after controlling for word-frequency and syntactic structure. They also found that the frequency of sequences of parts-of-speech (e.g., determine-noun-verb) also affected readers eye-movement patterns. We controlled for syntactic structure in the present work, but future work in both the visual and auditory modalities should aim to isolate the roles played by specific word sequences and sequences of parts-of-speech in modulating sentence processing. The same holds for word lengths (both length in letters and auditory durations), which although highly

correlated with parts-of-speech, can according to Snell and Theeuwes, play an independent role.

Finally, under the commonly held assumption that words are the building blocks of language use (e.g., Pinker, 1998; Pinker & Ullman, 2002), we need to address the issue of the repeated absence of word-frequency effects when phrase-frequency is controlled for, as found in the present study and in prior research (Janssen and Barber, 2012; Siyanova-Chanturia et al., 2011). Here we tested one possible explanation – that word-frequency was confounded with cloze probability (see also Siyanova-Chanturia et al., 2011). The results of Experiment 3 revealed that, although the phrases containing high-frequency words did indeed have lower cloze probabilities on average, the word-frequency effect remained non-significant when entering these probabilities as a covariate in the mixed-model analyses. We suspect that both probabilistic constraints and syntactic constraints dilute the effects of word frequency when these are measured using a global measure of sentence processing such as the grammatical decision task. One means to test this hypothesis in future research would be test for word-frequency effects using a measure of single word processing while listening to sequences of words (e.g., detecting a verb: Dufour et al., in press).

In sum, we found, for the first time, a phrase-frequency effect in speeded grammatical decisions made to sequences of 4 words presented auditorily. Contrary to prior research we found this effect in an experiment that used a wide variety of syntactic structures and using a corpus of spoken language to measure phrase-frequencies. However, we failed to observe an effect of content word-frequency. We suspect that the phrase-frequency effect observed in our experiment is at least partly driven by probabilistic constraints rather than chunk frequency,

and that the absence of a frequency effect for content words reflects the dominant role played by function words in rapidly deriving a primitive syntactic structure that is used to initiate grammatical decisions.

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Table 1: Characteristics of the phrases used in Experiment 1 (mean values with frequency ranges in parentheses).

	<b>Phrase- frequency</b>	Word 1 frequency	Word 2 frequency	Word 3 frequency	Word 4 frequency	Phrase duration
High-frequency condition	<b>3.08</b> <b>(2.23-3.73)</b>	3.58 (1.83-4.41)	3.25 (1.18-4.36)	3.65 (2.04-4.40)	2.33 (1.59-3.44)	900
Low-frequency condition	<b>1.60</b> <b>(1.56-1.75)</b>	3.58 (1.83-4.41)	3.36 (2.16-4.36)	3.61 (2.15-4.40)	2.29 (0.70-3.54)	919

Note: in log for Frequency; in ms for duration

Table 2: Characteristics of the phrases used in Experiment 2 (mean values with frequency ranges in parentheses).

	Phrase- frequency	Word 1 frequency	<b>Word 2 frequency</b>	Word 3 frequency	<b>Word 4 frequency</b>	Phrase duration
High-frequency condition	1.86 (1.56-2.69)	3.81 (1.83-4.41)	<b>2.52</b> <b>(2.19-3.05)</b>	4.23 (3.25-4.40)	<b>2.52</b> <b>(2.21-2.94)</b>	983
Low-frequency condition	1.88 (1.57-2.70)	3.81 (1.83-4.41)	<b>1.23</b> <b>(0.17-1.69)</b>	4.23 (3.25-4.40)	<b>1.17</b> <b>(0.33-1.64)</b>	986

Note: in log for Frequency; in ms for duration

Table 3: Characteristics of the phrases in the additional analyses of Experiment 3 (mean values with ranges in parentheses).

	Phrase-frequency	Word 1 frequency	Word 2 frequency	Word 3 frequency	Word 4 frequency	Phrase duration	Cloze probability
Experiment 1							
High-frequency condition	<b>3.10</b> <b>(2.45-3.73)</b>	3.37 (1.83-4.41)	3.48 (2.14-4.36)	3.66 (2.99-4.36)	2.34 (1.59-3.44)	893	<b>0.20</b> <b>(0-0.73)</b>
Low-frequency condition	<b>1.61</b> <b>(1.56-1.72)</b>	3.61 (2.06-4.41)	3.43 (2.31-4.36)	3.43 (2.15-4.36)	2.44 (1.41-3.50)	901	<b>0.19</b> <b>(0-0.68)</b>
Experiment 2							
High-frequency condition	1.93 (1.56-2.69)	3.77 (1.83-4.23)	<b>2.51</b> <b>(2.19-2.92)</b>	4.26 (3.25-4.40)	<b>2.51</b> <b>(2.21-2.94)</b>	997	<b>0.24</b> <b>(0.05-0.69)</b>
Low-frequency condition	1.89 (1.57-2.70)	3.77 (1.83-4.23)	<b>1.24</b> <b>(0.17-1.69)</b>	4.26 (3.25-4.40)	<b>1.13</b> <b>(0.33-1.56)</b>	989	<b>0.26</b> <b>(0.05-0.67)</b>

Note: in log for Frequency; in ms for duration

Appendix 1: Four-word phrases used in Experiment 1 (phrase-frequency manipulation)

<b>High-Frequency condition</b>	<b>Grammatical structure</b>	<b>Low-Frequency condition</b>	<b>Grammatical structure</b>
je peux tout expliquer	pro:per ver adv ver	je vais encore essayer	pro:per ver adv ver
donne moi ta main	ver pro:per adj:pos nom	crois en mon expérience	ver pro:per adj:pos nom
vous avez ma parole	pro:per ver adj:pos nom	je veux ton bonheur	pro:per ver adj:pos nom
vous avez cinq minutes	pro:per ver adj:num nom	on a deux options	pro:per ver adj:num nom
il était une fois	pro:per ver art:ind nom	tu es un as	pro:per ver art:ind nom
la voie est libre	art:def nom ver adj	le monde est dangereux	art:def nom ver adj
c'est bon signe	pro:dem ver adj nom	c'est juste impossible	pro:dem ver adj nom
je suis au courant	pro:per ver art:def nom	j'appelle les urgences	pro:per ver art:def nom
c'est ma faute	pro:dem ver adj:pos nom	c'est mon pantalon	pro:dem ver adj:pos nom
je fais mon travail	pro:per ver adj:pos nom	vous êtes ma mère	pro:per ver adj:pos nom
elle est venue ici	pro:per aux ver adv	j'ai tout risqué	pro:per aux adv ver
c'est mon père	pro:dem ver adj:pos nom	c'est mon médecin	pro:dem ver adj:pos nom
on a du boulot	pro:per ver art:def nom	je veux une famille	pro:per ver art:ind nom
allons boire un verre	ver ver art:ind nom	venez faire un tour	ver ver art:ind nom
j'ai une question	pro:per ver art:ind nom	nous avons des projets	pro:per ver art:ind nom
on peut le faire	pro:per ver pro:per ver	tu vas les tuer	pro:per ver pro:per ver
vous perdez votre temps	pro:per ver adj:pos nom	je suis votre roi	pro:per ver adj:pos nom
c'est une blague	pro:dem ver art:ind nom	c'est la maman	pro:dem ver art:def nom
tu devrais avoir honte	pro:per ver ver nom	il doit avoir faim	pro:per ver ver nom
je suis si contente	pro:per ver adv adj	je suis toujours prête	pro:per ver adv adj
il a été tué	pro:per aux ver ver	vous avez laissé faire	pro:per aux ver ver
j'en ai assez	pro:per pro:per ver adv	il en fait trop	pro:per pro:per ver adv
c'est la vérité	pro:dem ver art:def nom	c'est leur vie	pro:dem ver adj:pos nom
la salle de bain	art:def nom pre nom	le bureau de police	art:def nom pre nom
la scène de crime	art:def nom pre nom	la fête de demain	art:def nom pre nom
vous avez le droit	pro:per ver art:def nom	nous sommes les parents	pro:per ver art:def nom
le moment est venu	art:def nom aux ver	le type est mort	art:def nom aux ver
je suis vraiment désolé	pro:per aux adv adj	je suis déjà pris	pro:per aux adv adj
le dîner est servi	art:def nom aux ver	le plein est fait	art:def nom aux ver
je commence à comprendre	pro:per ver pre ver	tu veux à manger	pro:per ver pre ver

Note: pro:per = personal pronoun; pro:dem = demonstrative pronoun; art:def = definite article; art:ind = indefinite article; ver = verb; adv = adverb; aux = auxiliary; adj:pos = possessive adjective; adj:num = numeral adjective; nom = noun; pre = preposition.

Appendix 2: Four-word phrases used in Experiment 2 (word-frequency manipulation)

<b>High-Frequency condition</b>	<b>Grammatical structure</b>	<b>Low-Frequency condition</b>	<b>Grammatical structure</b>
le lieu de travail	art:def nom pre nom	le piquet de grève	art:def nom pre nom
la maison de maman	art:def nom pre nom	la veille de Noël	art:def nom pre nom
le chef de famille	art:def nom pre nom	le gala de charité	art:def nom pre nom
je connais ma fille	pro:per ver adj:pos nom	je tiendrai ma promesse	pro:per ver adj:pos nom
j'appelle ton père	pro:per ver adj:pos nom	j'apprécie ton geste	pro:per ver adj:pos nom
le temps est passé	art:def nom aux ver	le débat est clos	art:def nom aux ver
une personne de confiance	art:ind nom pre nom	une poupée de chiffon	art:ind nom pre nom
un problème de voiture	art:ind nom pre nom	un parcours de golf	art:ind nom pre nom
un monde à part	art:ind nom pre nom	un bac à sable	art:ind nom pre nom
un numéro de téléphone	art:ind nom pre nom	un tissu de mensonges	art:ind nom pre nom
l'été est fini	art:def nom aux ver	l'incident est clos	art:def nom aux ver
un mot de passe	art:ind nom pre nom	un bol de riz	art:ind nom pre nom
une femme de chambre	art:ind nom pre nom	une crise de nerfs	art:ind nom pre nom
une école de droit	art:ind nom pre nom	une barre de fer	art:ind nom pre nom
les gens sont fous	art:def nom ver adj	les chances sont minces	art:def nom ver adj
une partie de plaisir	art:ind nom pre nom	une botte de foin	art:ind nom pre nom
un film de guerre	art:ind nom pre nom	un conte de fées	art:ind nom pre nom
mon lit de mort	adj:pos nom pre nom	mon compagnon de cellule	adj:pos nom pre nom
une question de pouvoir	art:ind nom pre nom	une boule de poils	art:ind nom pre nom
un corps de femme	art:ind nom pre nom	un terrain de golf	art:ind nom pre nom
un enfant de dieu	art:ind nom pre nom	un morceau de viande	art:ind nom pre nom
une affaire de police	art:ind nom pre nom	une lampe de poche	art:ind nom pre nom
une fin de semaine	art:ind nom pre nom	une vague de chaleur	art:ind nom pre nom
une nuit d'amour	art:ind nom pre nom	une bourse d'études	art:ind nom pre nom
mon frère de sang	adj:pos nom pre nom	mon taux de sucre	adj:pos nom pre nom
son jour de chance	adj:pos nom pre nom	son champ de vision	adj:pos nom pre nom
l'heure de vérité	art:def nom pre nom	l'acte de vente	art:def nom pre nom
la garde à vue	art:def nom pre nom	la corde à linge	art:def nom pre nom
le cours d'histoire	art:def nom pre nom	le code d'accès	art:def nom pre nom
le bureau de papa	art:def nom pre nom	le champ de maïs	art:def nom pre nom

Note: pro:per = personal pronoun; art:def = definite article; art:ind = indefinite article; ver = verb; adj:pos = possessive adjective; adj = adjective; nom = noun; pre = preposition.

### Appendix 3: Four-word phrases used in the additional analyses of Experiment 3.

High-Frequency condition	Grammatical structure	Cloze	Low-Frequency condition	Grammatical structure	Cloze	
le dîner est servi	art:def nom aux ver	0.349	le plein est fait	art:def nom aux ver	0.679	<b>Experiment 1</b>
c' est bon signe	pro:dem ver adj nom	0.031	c' est juste impossible	pro:dem ver adj nom	0.014	<b>Experiment 1</b>
c' est ma faute	pro:dem ver adj:pos nom	0.012	c' est mon pantalon	pro:dem ver adj:pos nom	0	<b>Experiment 1</b>
c' est mon père	pro:dem ver adj:pos nom	0.082	c' est leur vie	pro:dem ver adj:pos nom	0.147	<b>Experiment 1</b>
je suis vraiment désolé	pro:per aux adv adj	0.302	je suis déjà pris	pro:per aux adv adj	0.058	<b>Experiment 1</b>
il a été tué	pro:per aux ver ver	0.082	vous avez laissé faire	pro:per aux ver ver	0.037	<b>Experiment 1</b>
j' en ai assez	pro:per pro:per ver adv	0.212	il en fait trop	pro:per pro:per ver adv	0.57	<b>Experiment 1</b>
vous avez ma parole	pro:per ver adj:pos nom	0.452	je veux ton bonheur	pro:per ver adj:pos nom	0.083	<b>Experiment 1</b>
je fais mon travail	pro:per ver adj:pos nom	0.229	vous êtes ma mère	pro:per ver adj:pos nom	0.107	<b>Experiment 1</b>
je suis si contente	pro:per ver adv adj	0.151	je suis toujours prête	pro:per ver adv adj	0.176	<b>Experiment 1</b>
on a du boulot	pro:per ver art:def nom	0	nous sommes les parents	pro:per ver art:def nom	0.036	<b>Experiment 1</b>
j' ai une question	pro:per ver art:ind nom	0.071	nous avons des projets	pro:per ver art:ind nom	0.012	<b>Experiment 1</b>
je commence à comprendre	pro:per ver pre ver	0.153	tu veux à manger	pro:per ver pre ver	0.278	<b>Experiment 1</b>
on peut le faire	pro:per ver pro:per ver	0.108	tu vas les tuer	pro:per ver pro:per ver	0.073	<b>Experiment 1</b>
allons boire un verre	ver ver art:ind nom	0.733	venez faire un tour	ver ver art:ind nom	0.547	<b>Experiment 1</b>
le lieu de travail	art:def nom pre nom	0.145	le piquet de grève	art:def nom pre nom	0.347	<b>Experiment 2</b>
la maison de maman	art:def nom pre nom	0.108	la veille de Noël	art:def nom pre nom	0.598	<b>Experiment 2</b>
j' appelle ton père	pro:per ver adj:pos nom	0.547	j' apprécie ton geste	pro:per ver adj:pos nom	0.058	<b>Experiment 2</b>
une personne de confiance	art:ind nom pre nom	0.655	une poupée de chiffon	art:ind nom pre nom	0.169	<b>Experiment 2</b>
un problème de voiture	art:ind nom pre nom	0.071	un parcours de golf	art:ind nom pre nom	0.086	<b>Experiment 2</b>
un monde à part	art:ind nom pre nom	0.171	un bac à sable	art:ind nom pre nom	0.631	<b>Experiment 2</b>
un numéro de téléphone	art:ind nom pre nom	0.694	un tissu de mensonges	art:ind nom pre nom	0.277	<b>Experiment 2</b>
un mot de passe	art:ind nom pre nom	0.238	un bol de riz	art:ind nom pre nom	0.233	<b>Experiment 2</b>
une femme de chambre	art:ind nom pre nom	0.11	une crise de nerfs	art:ind nom pre nom	0.259	<b>Experiment 2</b>
les gens sont fous	art:def nom ver adj	0.081	les chances sont minces	art:def nom ver adj	0.36	<b>Experiment 2</b>
une partie de plaisir	art:ind nom pre nom	0.153	une botte de foin	art:ind nom pre nom	0.4	<b>Experiment 2</b>
un film de guerre	art:ind nom pre nom	0.165	un conte de fées	art:ind nom pre nom	0.671	<b>Experiment 2</b>
mon lit de mort	adj:pos nom pre nom	0.096	mon compagnon de cellule	adj:pos nom pre nom	0.06	<b>Experiment 2</b>
un corps de femme	art:ind nom pre nom	0.114	un terrain de golf	art:ind nom pre nom	0.047	<b>Experiment 2</b>
une affaire de police	art:ind nom pre nom	0.048	une lampe de poche	art:ind nom pre nom	0.225	<b>Experiment 2</b>
mon frère de sang	adj:pos nom pre nom	0.61	mon taux de sucre	adj:pos nom pre nom	0.269	<b>Experiment 2</b>
son jour de chance	adj:pos nom pre nom	0.265	son champ de vision	adj:pos nom pre nom	0.259	<b>Experiment 2</b>
l' heure de vérité	art:def nom pre nom	0.095	l' acte de vente	art:def nom pre nom	0.06	<b>Experiment 2</b>
la garde à vue	art:def nom pre nom	0.426	la corde à linge	art:def nom pre nom	0.071	<b>Experiment 2</b>
le bureau de papa	art:def nom pre nom	0.096	le champ de maïs	art:def nom pre nom	0.099	<b>Experiment 2</b>