

Effects of metric hierarchy and rhyme predictability on word duration in *The Cat in the Hat*

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Abstract

Word durations convey many types of linguistic information, including intrinsic lexical features like length and frequency and contextual features like syntactic and semantic structure. The current study was designed to investigate whether hierarchical metric structure and rhyme predictability account for durational variation over and above other features in productions of a rhyming, metrically-regular children's book: *The Cat in the Hat* (Dr. Seuss, 1957). One-syllable word durations and inter-onset intervals were modeled as functions of segment number, lexical frequency, word class, syntactic structure, repetition, and font emphasis. Consistent with prior work, factors predicting longer word durations and inter-onset intervals included more phonemes, lower frequency, first mention, alignment with a syntactic boundary, and capitalization. A model parameter corresponding to metric grid height improved model fit of word durations and inter-onset intervals. Specifically, speakers realized five levels of metric hierarchy with inter-onset intervals such that interval duration increased linearly with increased height in the metric hierarchy. Conversely, speakers realized only three levels of metric hierarchy with word duration, demonstrating that they shortened the highly predictable rhyme resolutions. These results further understanding of the factors that affect spoken word duration, and demonstrate the myriad cues that children receive about linguistic structure from nursery rhymes.

Keywords: meter, metric hierarchy, predictability, duration, rhyme, nursery rhyme

1 Introduction

Children's literature across languages contains many examples of metrically-regular, rhyming texts (Arleo, 2006; Brailoiu, 1984; Burling, 1966). Literacy experts have suggested that the structure of these texts enhances children's literacy development (e.g., Irwin, Moore, Tornatore, & Fowler, 2012), and publishers and educators tout nursery rhymes as ideal first readers. However, there is limited experimental evidence supporting the claim that these texts improve reading ability. To clarify the contribution that nursery rhymes make to early reading skill, we first need to understand what type of information readers of nursery rhymes are exposed to through their interaction with metrically-regular, rhyming texts, and how this information differs from prose. Moreover, because children routinely *hear* these texts before they read them, we need to understand how they are produced by readers. In the current study, I investigated how metric structure and rhyme in a classic children's book, *The Cat in the Hat* (Dr. Seuss, 1957), affect prosody in adult productions.

Despite the ubiquity of metrically-regular, rhyming children's books, there have been few systematic investigations of whether or how their productions differ from prose productions. What studies have been carried out have investigated to what extent the prosodic hierarchy (Liberman & Prince, 1977; Hayes, 1989; Nespor & Vogel, 2007; Selkirk, 1984) is realized in metric verse. The prosodic hierarchy is primarily determined by a sentence's phonological structure (Nespor & Vogel, 2007). Although it is correlated with syntactic structure, it is not identical to it (e.g., Gee & Grosjean, 1983; Shattuck-Hufnagel & Turk, 1996). The levels of the prosodic hierarchy are *words*, *clitic phrases*, which are groupings of words that tend to overlap in production, *phonological* or *accentual phrases*, which are domains within which speakers place accents, and *intonational phrases*, which are phrases bounded by tonal or temporal disjuncture. These levels have been argued to form a strict hierarchy, such that each

level contains the only the level of the hierarchy beneath it (Hayes, 1989; Nespor & Vogel, 2007).

The prosodic hierarchy has been shown to influence production behavior for both prose and poetry. In prose contexts, speakers increase word duration with position in up to four levels of the prosodic hierarchy (Wightman, Shattuck-Hufnagel, Ostendorf, & Price, 1992). In addition, the prosodic hierarchy has been shown to account for durational variation of words in sentences matched on syntactic structure (Ferreira, 1993). In poetic contexts, speakers have been shown to produce syllables that align with higher levels of the hierarchy with longer durations than those that align with lower levels (Hayes & Kaun, 1996). However, although the prosodic hierarchy is correlated with the metric structure of text, it is not isomorphic with it. As such, there has been no systematic evaluation of the influence of hierarchical metric structure on speech. The goal of the current study is to provide such an evaluation.

One very well-known example of metrically-regular, rhyming text in English children's literature is *The Cat in the Hat* by Theodor Geisel (1957), published under Geisel's pen name Dr. Seuss. Geisel was given a list of 300+ words that every six-year-old should know, and used 236 unique words (220 of which were monosyllabic) mostly from that list to write the book (Nel, 2004). In an effort to make *The Cat in the Hat* a more entertaining reading primer than the standard "Dick and Jane" readers of the time, *The Cat in the Hat* is written primarily in anapestic tetrameter: lines (1A, 1B) consist of four anapestic (weak-weak-**strong**) feet. Two couplets form a stanza, and the last syllables of the two lines within a stanza (e.g., *all*, *fall*) rhyme.

1) A: "Put me **down**!" said the **fish**.

*This is **no** fun at **all**!*

B: Put me **down**!" said the **fish**.

69 “I do **NOT** wish to *fall*.”

70 To describe the metric structure of *The Cat in the Hat*, I utilized the metrical grid structure
 71 conventions of Fabb and Halle (2008), which are based in part on proposals by Liberman and
 72 Prince (1977) and Idsardi (1992). Under Fabb and Halle’s (2008) proposal, syllables are
 73 assigned to a grid using a set of iterative rules. Fabb and Halle refer to the levels as
 74 "Gridlines" which start at level 0; for ease of interpretation, they are referred to as "Metric
 75 Levels" and begin numbering at level 1. The application of these rules to a stanza from *The*
 76 *Cat in the Hat* is presented in Table 1. First, each syllable, regardless of accent status, is
 77 assigned an asterisk on Metric Level 1. Next, syllables are grouped on Metric Level 2 using
 78 parentheses which face left or right depending on whether the metric feet are left-headed (i.e.,
 79 with the heavy syllable on the left, including *trochees* and *dactyls*) or right-headed (i.e., with
 80 the heavy syllable on the right, including *iamb*s and *anapests*). For lines composed of left-
 81 headed feet, syllables are grouped from left to right; for right-headed feet, syllables are
 82 grouped from right to left. Here I focus only on the rules for right-headed feet, as *The Cat in*
 83 *the Hat* is composed of anapests. To create Metric Level 2, the heads of Metric Level 1 are
 84 grouped into ternary right-headed structures which project their heads to Metric Level 2, as
 85 indicated by the location of asterisks on Metric Level 2. To generate groupings on Metric
 86 Level 3 and above, the heads on the Metric Level below are grouped into binary, right-
 87 headed groups, the boundaries of which are indicated by left-facing parentheses. For
 88 example, *down* is the head of a group on Metric Level 2, but *fish* is the head of the group
 89 containing *down* on Metric Level 3. The metric grid is complete when there is no way to
 90 decrease the number of asterisks on a gridline; that is, with a Metric Level containing only 1
 91 asterisk. For the first line in Table 1, this condition is met at Metric Level 4.

92 Application of Fabb and Halle’s (2008) iterative grouping rules to one line of *The Cat in the*
 93 *Hat* results in a metrical grid consisting of four hierarchical levels, and Fabb and Halle state

that lines requiring four or more levels (i.e., with more than twelve syllables) are rare, perhaps due to memory constraints. However, metric structure in music is routinely computed over larger distances (Lerdahl & Jackendoff, 1983; Todd, 1985). In the current analyses, therefore, the iterative grouping rules are extended to two lines (i.e., one stanza) to test the hypothesis that readers generate metric grid structures that take into account more than one line of text. This extension results in five levels of metric structure (Table 1).

Table 1

Metric grid assignment for one stanza of *The Cat in the Hat* based on Fabb and Halle (2008).

	Put	me	down	said	the	fish	this	is	no	fun	at	all
Metric Level 1)*	*	*)	*	*	*)	*	*	*)	*	*	*)
Metric Level 2)*			*)			*			*)
Metric Level 3)*						*)
Metric Level 4)*
Metric Level 5												
	Put	me	down	said	the	fish	I	do	not	wish	to	fall
Metric Level 1)*	*	*)	*	*	*)	*	*	*)	*	*	*)
Metric Level 2)*			*)			*			*)
Metric Level 3)*						*)
Metric Level 4												*)
Metric Level 5												*

Note: Asterisks indicate syllables that head groups on the next-lowest metric level. Parentheses group syllables on a level; left-facing parentheses demarcate the boundaries of a right-headed group.

Fabb and Halle (2008) explicitly state that their model is not one of performance, in that they don't intend for it to predict speaker behavior or to account for the influence of other forms of linguistic knowledge on productions of metric structure. In fact, there have been few systematic investigations of how hierarchical metric structure is realized in speech, limited to the repetition of short (four-word) segments (Cummins & Port, 1998). However, there are two compelling reasons to believe that speakers will provide cues to metric structure in continuous speech: speakers realize many aspects of linguistic structure with prosody, and

124 both experienced and novice musicians realize hierarchical metric structure in musical
 125 productions.

126 First, extensive empirical research demonstrates that speakers routinely signal aspects of
 127 linguistic structure using prosodic cues like prominence and phrasing (see reviews by
 128 Fletcher, 2010 and Wagner & Watson, 2010). For example, speakers signal the presence of
 129 new or important information with accents, characterized by longer duration (Fry, 1955;
 130 Klatt, 1976), greater intensity (Fry, 1955), and pitch movement (Breen, Fedorenko, Wagner,
 131 & Gibson, 2010). Moreover, speakers use durational lengthening to cue lexical boundaries
 132 (Beckman & Edwards, 1990; Turk and Shattuck-Hufnagel, 2000) and syntactic boundaries
 133 (Watson & Gibson, 2004; Wightman, et al., 1992). Finally, and most relevant to the current
 134 investigation, speakers have been shown to use durational cues to maintain rhythmic structure
 135 in both prose speech (Lehiste, 1972; Beckman & Edwards, 1990; Cummins & Port, 1998)
 136 and poetic speech (Wagner, 2013).

137 Second, evidence from music performance demonstrates that musicians signal metric
 138 structure using a variety of acoustic features. For example, notes in metrically strong
 139 positions are produced with relatively longer durations than similar length notes in non-
 140 prominent positions (Clarke, 1985; Drake & Palmer, 1993; Palmer & Kelly, 1992; Repp,
 141 1992; Sloboda, 1983). Moreover, metric structure affects durational variation at multiple
 142 hierarchical levels (Palmer, 1996; Todd, 1985, 1989). For example, Todd (1985)
 143 demonstrated that the amount of *rubato* (slowing) at each note position is proportional to that
 144 note's position in a hierarchical structure of tonal stability, where position is determined by
 145 the degree of structural embedding. At each level of embedding, the ending of the phrase is
 146 realized with an increase in duration equal to the depth of encoding multiplied by a constant.
 147 Although Todd presents no quantitative assessment of the rubato model's fit to specific

productions, data from four performances suggest that pianists use durational variation to realize up to seven levels of hierarchical metric structure.

In addition to exploring the question of how speakers realize metric structure in their productions, we can also use productions of *The Cat in the Hat* to investigate how metric structure interacts with syntactic structure. Speakers generally lengthen words at syntactic boundaries and this lengthening increases with the size of the material before and after the boundary (Watson & Gibson, 2004; Wightman, et al., 1992). However, in metrically-regular texts, syntactic boundaries do not always align with metric structure. In these cases, called *enjambment*, a metric boundary occurs at a location where there is no syntactic boundary. In (2), for example, the word *saw* in lines two and four is the location of a metric head on Metric Level 3, but not a syntactic boundary. In fact, as the following word *him* is the argument of the verb *saw*, models of the relationship between syntactic structure and prosodic structure predict a very low probability of a prosodic boundary in this location (Selkirk, 1984; Watson, Breen & Gibson, 2006).

2) *We looked!*
 Then we saw him step in on the mat!
 We looked!
 And we saw him!
 The Cat in the Hat!

Tsur (2012) argues that speakers convey both metric structure and syntactic structure in cases of enjambment by producing simultaneous cues to both continuity and discontinuity. Specifically, speakers signal continuity by not pausing between the last word of an enjambment and the following word, but simultaneously signal discontinuity with relative lengthening of the vowel in a word at the end of an enjambment. In (2), Tsur would predict

that speakers would lengthen *saw* in line 2, but would not pause between *saw* and *him*. This claim predicts differential effects of syntactic and metric structure on production depending on whether disjuncture is operationalized as the lengthening of a word, or as the introduction of silence after a word. Therefore, in the current study, I will consider effects of metric structure on both word duration and inter-onset interval—the duration of the word and any following silence.

Although durational measurements can provide information about the metric structure of productions, duration in speech, operationalized as either word duration or inter-onset interval, is affected by many other factors (Klatt, 1976; Fletcher, 2010; Turk & Shattuck-Hufnagel, 2014). Therefore, a model to assess metric effects on duration must also account for three general categories of factors that affect single word duration: *intrinsic factors* that are specific to the word itself; *contextual factors* which characterize the local environment of the word; and *global factors* which characterize the context in which the speech was produced.

The intrinsic factors assessed in the current study are word length, word class, and lexical frequency. Words with more phonemes are produced with longer durations than those with fewer phonemes (Bell, Brenier, Gregory, Girand, & Jurafsky, 2009). Open-class (content) words are produced with longer durations than closed-class (function) words (Bell, et al., 2009). More frequent words are produced with shorter durations than less frequent words (Aylett & Turk, 2004; Jurafsky, Bell, Gregory, & Raymond, 2001; Bell et al., 2009). Moreover, these intrinsic factors have interactive effects on word duration; for example, frequency effects are larger for open-class than closed-class words (Segalowitz & Lane, 2000; Bell, et al., 2009).

The contextual factors known to affect word duration assessed in the current study are repetition, syntactic structure, and semantic structure. Repetition affects duration such that words are shortened on their second mention (Fowler & Housum, 1987; Anderson & Howarth, 2002). Words that occur at syntactic boundaries are produced with longer durations than those that occur in phrase-medial positions (Klatt, 1976; Breen, Watson, & Gibson, 2011; Wightman, et al., 1992). Semantic context affects word duration such that words are longer when they are important in the discourse (Beckman, 1986; Breen, et al., 2010). In text, semantic context is often signaled with text emphasis, as implemented through capitalization, italics, or bolding (Fraundorf, Benjamin, & Watson, 2013). In *The Cat in the Hat*, Dr. Seuss uses capitalization to mark words which are contextually prominent (e.g., *NOT* in (1)).

The global factor assessed in the current study was the presence of an audience of children. Although prior studies have demonstrated that speakers tend to produce child-directed speech (CDS) at a slower rate than adult-directed speech (ADS) (e.g., Fernald & Simon, 1984), more recent work demonstrates that, rather than being slower overall, CDS in fact has more phrase-final lengthening (Martin, Igarashi, Jincho, Mazuka, 2016; Church, Bernhardt, Pichora-Fuller, & Shi, 2005), as well as greater lengthening for semantically-important words (Ko & Soderstrom, 2013).

In the current study, I assessed the effects of hierarchical metric structure on word durations in a novel corpus of adult productions of *The Cat in the Hat* while simultaneously assessing the aforementioned intrinsic, contextual, and global factors known to predict duration in speech. The text is ideal for such an investigation as it is composed primarily of high frequency one-syllable words, which avoids the complication that many predictors of word length interact in multi-syllabic words (e.g., Turk & Shattuck-Hufnagel, 2007). Moreover, *The Cat in the Hat* features a consistent metric structure, simple syntactic structure, and

219 textual cues to semantic structure, allowing for simultaneous investigation of all of these
 220 factors.

221 **2 Method**

222 **2.1 Participants**

223 Eighteen Mount Holyoke students between the ages of 18 and 35, all of whom identified as
 224 female, participated in the current study. All participants were native speakers of American
 225 English, meaning that they had been speaking English in the United States since at least the
 226 age of five. One participant later identified herself as a non-native speaker, so her data were
 227 excluded from analyses. Therefore, a total of seventeen speakers contributed data to the
 228 current analyses. Participants received course credit in exchange for their participation.

229 **2.2 Material**

230 *The Cat in the Hat* is a 61-page illustrated book written primarily in anapestic tetrameter.
 231 Seventy stanzas are comprised of two lines of four anapests each (as in (1)). In addition, there
 232 are six single lines in the text. In two cases, these lines rhyme internally (e.g., *And then*
 233 *something went BUMP! How that bump made us jump!*). In the other four cases, the final
 234 word of the single line rhymes with the preceding stanza. Of the 236 unique lexemes that
 235 make up the text, 220 are monosyllabic, fifteen are disyllabic, and one (*another*) is trisyllabic.

236 **2.3 Procedure**

237 Participants were recorded reading the book aloud in its entirety without breaks in one of
 238 two randomly assigned locations. Eight participants read the book to an audience of
 239 preschool students (ages 4-5-years old) in a quiet classroom. Nine participants read the
 240 book without an audience in a quiet room. All participants were recorded using a Shure
 241 SM10 head-mounted microphone and a Rolls MP13 Mini-mic pre-amplifier at a sampling
 242 rate of 44100 Hz with 16-bit resolution. Participants read from a hardcover copy of the

book and were given no specific instructions on how to read the text, other than to read it aloud. All participants provided informed consent before they participated, and parents of the children who listened to the book provided written assent for their children's participation.

2.3.1 Acoustic measures

All productions were force-aligned with the book text using Praat (Boersma & Weenink, 2016) and Prosodylab-Aligner (Gorman, Howell, & Wagner, 2011), then hand-corrected. These alignments included annotation of word onsets and offsets, and periods of silences between words. Using Praat, I extracted the word duration and inter-onset interval for each word; the former is the interval between word onset and word offset, the latter is the interval between the onset of one word and the onset of the following word. The inter-onset interval is therefore the sum of the word duration and any following silence. I excluded the final word on each page from analysis to avoid including the time it takes to turn the page, which would artificially inflate the inter-onset interval measure. This constraint resulted in the exclusion of 40 words from the text per reader, equivalent to 680 data points from the corpus. A limitation of this approach is that, because there are only 76 stanzas in the book, excluding 40 page-final words resulted in a loss of measurements from more than half of the stanza-final words in the corpus. To present a full picture of the whole corpus, I modeled word duration both with and without page-final words. The results did not differ across these measurements, so I report only the results from the corpus without page-final words.

For individual speakers, I excluded disfluent word productions, extra words produced in incorrectly-read stanzas, and words produced with durations greater than three standard deviations above or below the mean for that speaker. In sum, these exclusions resulted in data loss of 754 words out of a possible 26792, or 2.8% of the total.

2.3.2 *Text Annotation*

The text of the book was annotated in a variety of ways, reflecting the segmental, lexical, metric, syntactic, and semantic characteristics of the text. To simplify analyses, investigation was limited to one-syllable words, which resulted in an exclusion of 16 out of the 236 unique lexemes, or 49 out of 1625 total words.

2.3.2.1 *Segment Number*

Using the MRC Psycholinguistic Database (Coltheart, 1981), the number of phonemes in each word was annotated. The 220 one-syllable words in the book range from 1-7 phonemes ($M = 2.98$; $SD = 0.80$).

2.3.2.2 *Word Class*

Each word in the book was annotated according to word class. Open-class words are nouns, verbs, and adjectives; closed-class words include auxiliary verbs, determiners, conjunctions, pronouns, and prepositions. Of the 1576 one-syllable words in the book, 542 are open-class words and 1034 are closed-class words.

2.3.2.3 *Lexical Frequency*

The frequency of each word was calculated using the Kučera-Francis (K-F) norms (Francis & Kučera, 1982), as implemented in the MRC Psycholinguistic Database (Coltheart, 1981). Twenty words in the text did not have raw K-F frequencies; for those words that were simple plural forms ($N = 15$; e.g., books, bumps, games) or regularly-inflected verbs ($N = 3$; asked, looked, picked) I substituted the K-F frequency for the singular or infinitival form of the word. There was no frequency information available for the words *plop* or *playthings*, so these words were not included in the regressions. Raw frequencies ranged from 1 (kite)

to 1635 (new) for open-class words and 144 (yes) to 69,971 (the) for closed-class words. These values were log-transformed; the resulting frequencies ranged from 0 to 11.16 ($M = 5.82$; $SD = 2.15$).

2.3.2.4 *Syntactic Structure*

The text was annotated using the Left-Right Boundary (LRB) model (Breen, Watson, & Gibson, 2011; Watson & Gibson, 2004). This algorithm posits a higher probability of a phrase boundary with increases in the size of the material the speaker has just produced (the left-hand side) and increases in what they are going to produce (the right-hand side), with the underlying assumption that boundaries allow the speaker to recover from having just produced sentence material and to plan upcoming information. LRB weights were determined as follows: first, the book was divided into phonological phrases, defined as content words and any preceding function words, and all words within these phrases were assigned weights of 0, as speakers rarely place boundaries within phonological phrases (Breen, et al., 2011). Words coinciding with the end of a phonological phrase were assigned a left-hand size (LHS) weight equal to the number of phonological phrases in the largest completed syntactic constituent in the current sentence, and a right-hand size (RHS) weight equal to the number of phonological phrases in the largest upcoming syntactic constituent in the current sentence. For example, the LHS weight of 3 for *Hat* in Table 2 reflects that fact that the largest completed constituent (*Tell / that Cat / in the Hat*) is composed of three phonological phrases. The RHS weight of 3 for this word reflects that fact that the largest upcoming constituent (*you / do not want / to play*) is composed of three phonological phrases. If the upcoming constituent was an argument of the current word, the LRB weight was 0, reflecting the fact that speakers rarely place boundaries between heads and their arguments (Ferreira, 1988; Watson, Breen, & Gibson, 2006). For example, the LRB weight for *Tell* is 0 because *that Cat* is an argument of *Tell*. The final LRB weight was computed as the sum of the LHS and RHS

314 weights, but was capped at 5 to reflect the fact that phrase boundaries are highly likely after
315 four phonological phrases. Sentence-final words did not have an RHS weight.

316 Table 2

317 Example of the LRB weights computed for a single line of text

318	<i>Word</i>	<i>LHS weight (phrases counted)</i>	<i>RHS weight (phrases counted)</i>	<i>LRB (LHS + RHS)</i>
319	Tell	0^	0^	0
320	that	0*	0*	0
321	Cat	1 ("that Cat")	1 ("in the Hat")	2
322	in	0*	0*	0
323	the	0*	0*	0
324	Hat	3 ("tell"; "that cat"; "in the hat")	3 ("you"; "do not want"; "to play")	5 (6)
325	you	1 ("you")	2 ("do not want"; "to play")	3
326	do	0*	0*	0
327	not	0*	0*	0
328	want	0^	0^	0
329	to	0*	0*	0
330	play	5	0 (sentence-final)	5

331 * indicates words that are followed by a word within the same phonological phrase; ^ indicates words that are in a head-argument relationship
 332 with the upcoming word.

333

334 **2.3.2.5 Text Emphasis**

335 A total of 26 words (16 unique lexical items) were written in CAPS. Each word without
 336 such text emphasis was coded as 0, and each word with text emphasis was coded with 1.

337 **2.3.2.6 Intra-stanza Repetition**

338 Each word was coded to indicate whether it was a repetition within that stanza. For
 339 example, the words *Put me down said the fish* in (1B) are predicted to be shortened because
 340 the same words were produced in the preceding couplet. These words were labeled with 1,
 341 while non-repeated words were labeled 0.

342 **2.3.2.7 Metric Structure**

343 Each word was annotated according to its weight in a hierarchical metric grid structure
 344 (Fabb & Halle, 2008), as shown in Table 1. There are five levels in total, where Metric
 345 Level 1 applies to the first two unstressed syllables of the anapest. Metric Level 2 applies
 346 to the foot of the first and third anapests in each of the lines. Metric Level 3 applies to the
 347 foot of the second anapest of each line; Metric Level 4 applies only to the foot of the fourth
 348 anapest of the first line. This word is always the first word in a rhyme pair (*all* in Table 1),
 349 which I will refer to subsequently as a *rhyme prime*. Metric Level 5 applies only to the foot
 350 of the fourth anapest of the second line. This word is always the second word of a rhyme
 351 pair (*fall* in Table 1), which I will refer to subsequently as a *rhyme target*.

352 **2.3.2.8 Enjambment**

353 To assess the interacting effects of metric structure and syntactic structure on duration, I
 354 annotated the text for instances of enjambment, defined as cases where a metric boundary
 355 occurs at a location where there is no syntactic boundary (e.g., *saw* in (2)). These cases only

ever occurred at Metric Level 3. Of 146 instances of Metric Level 3 in the text, 72 are cases of enjambment.

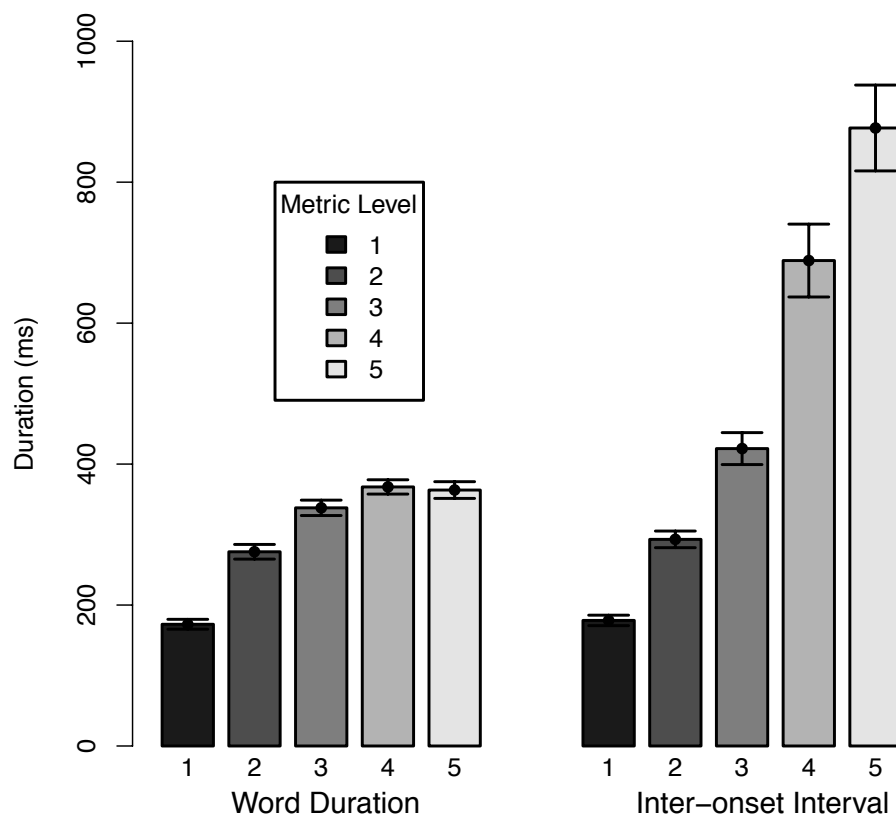
2.3.3 *Model-fitting*

The model-fitting procedure for all models reported in the paper was as follows: First, the data were fit on a word-by-word basis with the fully-saturated model including all fixed effects listed above, and a random effect of speaker. In addition, I attempted to fit a model including random slopes over speaker for each fixed effect and each interaction of fixed effects. This model did not converge, so I iteratively removed the random slope that accounted for the least variance and refit the model until it converged. Once the model converged, fixed effects were individually removed and, after each removal, the simpler model was compared to the more complex model in which it was nested using a likelihood ratio test (Baayen, Davidson, & Bates, 2008). Factors which accounted for significantly more variance in the more complex model were included in the final model.

3 Results

3.1 Word duration

Raw word durations for each level of the metric hierarchy are shown in Figure 1.



372

373 Figure 1: Values of word duration and inter-onset interval computed across five levels of
374 metric structure. Error bars indicate standard error across all durations within a level.

375

376 *3.1.1 Control model of word duration*

377 The goal of the statistical analysis was to determine whether the metric structure of *The*
378 *Cat in the Hat* accounts for durational variation over and above factors which have been
379 previously determined to explain duration variance in speech. Consistent with the method
380 of Bell, et al. (2009), I first generated a control regression model taking into account non-
381 metric factors known to predict word duration. The fixed factors in this model were
382 Audience, Segment Number, Word Class, Lexical Frequency, Syntactic Structure, Text
383 Emphasis, and Inter-stanza Repetition. Segment Number, Syntactic Structure, and Lexical
384 Frequency were continuous predictors; Audience, Word Class, Text Emphasis, and Intra-
385 stanza Repetition were centered categorical predictors. Based on previous investigations of
386 intrinsic factors influencing durations (Segalowitz & Lane, 2000; Bell, et al., 2009), I
387 tested whether interactions of Word Class and Lexical Frequency, and between Word Class
388 and Syntactic Structure, improved model fit. Based on previous investigations of contextual
389 and global factors influencing duration (Martin, et al., 2016; Church, et al., 2005; Ko &
390 Soderstrom, 2013), I tested whether interactions between Audience and Syntactic Structure,
391 Audience and Segment Number, and between Audience and Text Emphasis, improved
392 model fit.

393

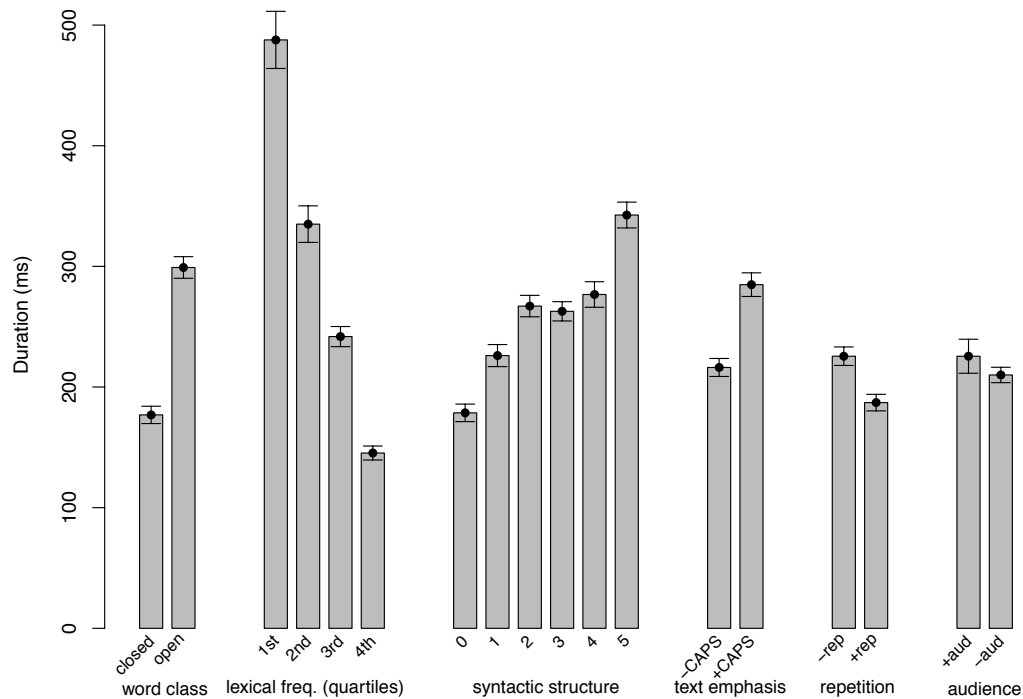


Figure 2: Word durations for intrinsic, contextual, and global factors in the final Control model of word duration. Error bars indicate standard error.

The random slopes included in the final Control model of word duration were Segment Number, Word Class, Syntactic Structure, Text Emphasis, and Intra-stanza Repetition. The final model parameters for the Control model of word duration appear in Table 3. The average durations of each intrinsic, contextual, and global factor are presented in Figure 2. The results of the Control duration model are consistent with previous results: The number of segments in a word influenced its duration such that more segments led to longer duration. Open-class words were produced with longer durations than closed-class words. Word duration increased as frequency decreased, and it increased with LRB weight. Finally, words presented with text emphasis (i.e., capitalization) were longer than those without. An interaction between Word Class and Lexical Frequency reflected the fact that

open-class words had a wider range of frequencies than closed-class words. An interaction between Word Class and Syntactic Structure reflected the fact that the duration of open-class words increased more at syntactic phrase boundaries than that of closed-class words. Although word durations were longer in the presence of an Audience, this factor did not interact with any other factors in the final model.

Table 3

Fixed effects in the final Control model of word duration

	Word Duration Control Model		
	<i>B</i>	<i>std. Error</i>	<i>t-value</i>
Fixed effects			
(Intercept)	246.14	9.45	26.04
Segment Number	25.08	1.72	14.60
Word Class	-37.37	5.13	-7.29
Lexical Frequency	-11.19	0.32	-34.59
Syntactic Structure	21.75	1.16	18.71
Text Emphasis	43.46	5.11	8.51
Intra-stanza Repetition	-3.89	1.56	-2.50
Audience	-27.65	11.59	-2.39
Word Class x Frequency	9.21	0.64	14.38
Word Class x Syntactic Structure	-1.68	0.54	-3.10

3.1.2 Metric Model of word duration

To determine whether the hierarchical metric structure of *The Cat in the Hat* affected word duration, the factor of Metric Level was added to the final Control model as both a fixed factor and as a random slope over participants. To assess whether each iterative increase in metric level led to an increase (or decrease) in word duration, I implemented backward difference coding of Metric Level. These contrasts allow for the comparison of each level of

the metric hierarchy to be compared to the adjacent level below it (Table 4). The random slopes included in the final Metric model of word duration were Metric Level, Segment Number, Text Emphasis. The final model parameters appear in Table 5.

Table 4

Contrast coefficients for backward difference coding of the Metric Level factor

	<i>Contrast 1</i>	<i>Contrast 2</i>	<i>Contrast 3</i>	<i>Contrast 4</i>
Metric Level 1	-0.80	-0.60	-0.40	-0.20
Metric Level 2	0.20	-0.60	-0.40	-0.20
Metric Level 3	0.20	0.40	-0.40	-0.20
Metric Level 4	0.20	0.40	0.60	-0.20
Metric Level 5	0.20	0.40	0.60	0.80

Model results demonstrate that speakers consistently realized three levels of metric hierarchy. Words aligned with Metric Level 2 were significantly longer than Metric Level 1, words aligned with Metric Level 3 were significantly longer than words aligned with Metric Level 2. Additionally, words aligned with Metric Level 4 (i.e., rhyme primes) were numerically, though not significantly, longer than words aligned with Metric Level 3. Finally, words aligned with Metric Level 5 (i.e., rhyme targets) were numerically, though not significantly, *shorter* in length than words aligned with Metric Level 4 (i.e., rhyme primes).

Table 5

Fixed effects in the final Metric model of word duration

	Word Duration Metric Model		
	<i>B</i>	<i>std. Error</i>	<i>t-value</i>
Fixed effects			
(Intercept)	275.54	11.10	24.83
Metric Level 2 vs. 1	37.59	4.41	8.52
Metric Level 3 vs. 2	37.80	5.56	6.80
Metric Level 4 vs. 3	8.52	5.90	1.44
Metric Level 5 vs. 4	-4.02	4.64	-0.87

Segment Number	23.07	1.82	12.66
Word Class	-61.38	4.60	-13.35
Lexical Frequency	-8.81	0.31	-27.98
Syntactic Structure	14.44	0.32	45.73
Text Emphasis	33.93	5.19	6.54
Audience	-15.66	7.99	-1.96
Word Class x Frequency	11.47	0.61	18.70
Word Class x Syntactic Structure	-2.15	0.53	-4.09

435

436 **3.2 Inter-onset interval**

437 To account for the role of silence in signaling disjuncture, I assessed to what extent metric
438 structure affected inter-onset interval. The average duration of inter-onset intervals for all
439 levels of metric hierarchy appear in Figure 1.

440 *3.2.1 Control Model of inter-onset interval*

441 As in the analysis of word duration, I first generated a Control model of inter-onset interval
442 where I tested the effects of non-metric factors. As before, the full model included fixed
443 effects of Segment Number, Word Class, Lexical Frequency, Syntactic Structure, Text
444 Emphasis, and Intra-stanza Repetition, and interactions of Word Class with Lexical
445 Frequency, and of Word Class with Syntactic Structure. The random slopes included in the
446 final model were Syntactic Structure, Word Class, and Text Emphasis, and interaction of
447 Audience x Text Emphasis.

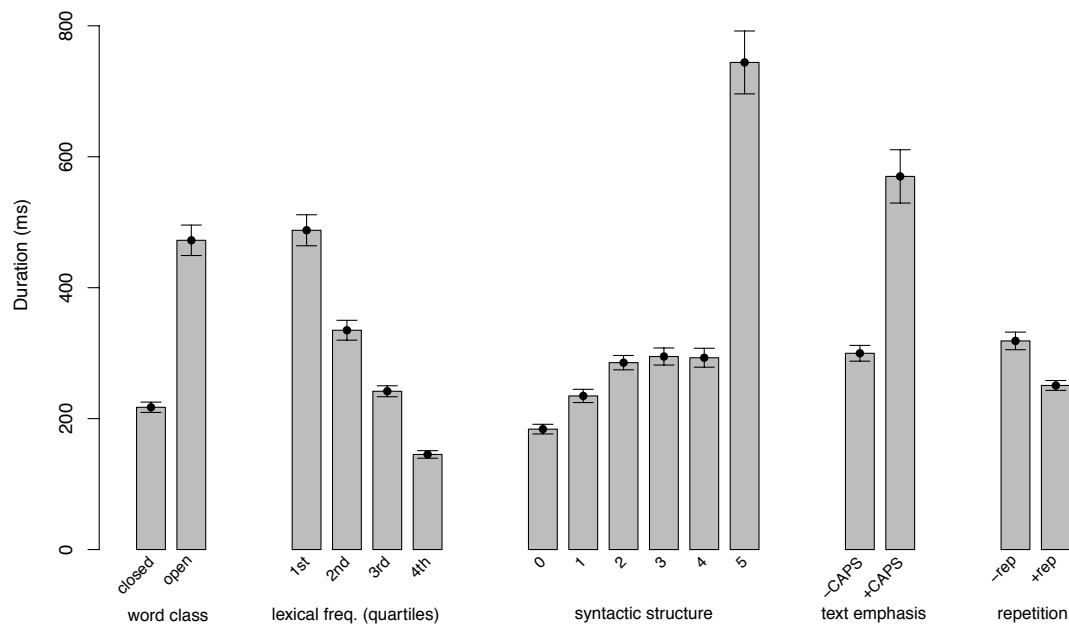


Figure 3. Durations for intrinsic and contextual factors in the Control model of inter-onset interval. Error bars indicate standard error.

The fixed effects factors included in the final Control model of inter-onset interval appear in Table 6 and the average durations for the intrinsic and contextual factors are presented in Figure 3. The parameters of this model were similar to those of the Control model of word duration (Table 3). As with word duration, inter-onset interval increased with segment number, text emphasis, and LRB weight, and it decreased with word repetition and increasing frequency.

Table 6

Fixed effects in the final Control model of inter-onset interval

Inter-onset interval Control Model

	<i>B</i>	<i>std. Error</i>	<i>t-value</i>
Fixed effects			
(Intercept)	270.71	14.38	18.82
Segment Number	22.84	1.47	15.57
Lexical Frequency	-13.79	0.66	-21.03
Syntactic Structure	55.22	4.94	11.19
Text Emphasis	40.34	8.85	4.56
Intra-stanza Repetition	-7.04	2.29	-3.08
Audience	-28.62	12.57	-2.28
Word Class x Frequency	2.17	0.63	3.46

3.2.2 Metric model of inter-onset interval

To determine whether the hierarchical metric structure of *The Cat in the Hat* affected inter-onset interval, I added the factor of Metric Level to the Control model. To assess whether each iterative increase in Metric Level led to an increase (or decrease) in word duration, I implemented backward difference coding of the Metric Level factor, such that each level of the factor was compared to the adjacent level below it (Table 4). The random slopes included in the final model were Meter Level, Segment Number, and Text Emphasis. The final model parameters are presented in Table 7.

Table 7

Fixed effects in the final Metric model of inter-onset interval

Inter-onset interval Metric Model			
	<i>B</i>	<i>std. Error</i>	<i>t-value</i>
Fixed effects			
(Intercept)	431.55	27.14	15.90
Metric Level 2 vs. 1	35.79	5.61	6.38
Metric Level 3 vs. 2	84.04	14.68	5.73
Metric Level 4 vs. 3	221.83	32.55	6.82
Metric Level 5 vs. 4	190.15	22.96	8.28
Audience	-32.01	10.07	-3.18
Segment Number	23.79	2.45	9.72
Lexical Frequency	-8.29	0.54	-15.35
Syntactic Structure	27.40	0.54	50.56
Text Emphasis	58.55	7.98	7.34

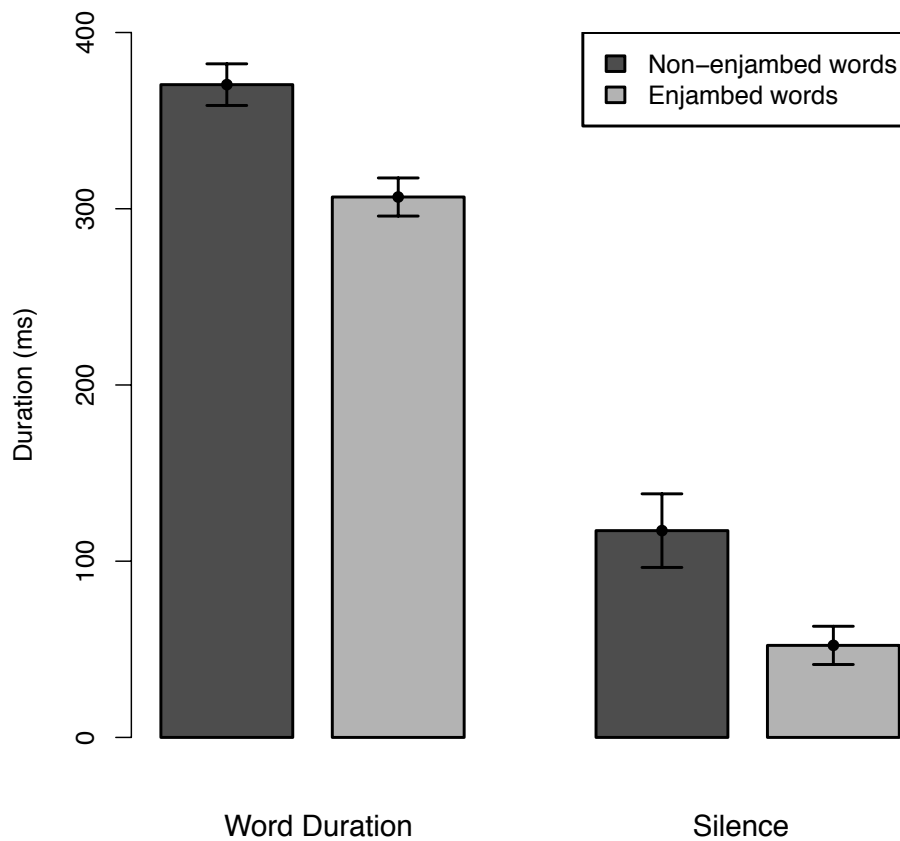
Word Class x Frequency	10.17	1.05	9.66
Word Class x Syntactic Structure	-2.80	0.90	-3.11

The results were again similar to those observed for word duration. However, unlike the Metric model of word duration, the Metric model of inter-onset interval indicated that speakers consistently realize five levels of metric hierarchy: Inter-onset intervals increased with the Metric Level to which they were aligned, such that Level 1 < Level 2 < Level 3 < Level 4 < Level 5.

3.3 Enjambment

As described above, Tsur (2012) demonstrated that speakers signal both continuity and discontinuity at locations of enjambment: discontinuity is signaled by lengthening of the enjambed word, while continuity is signaled by reduced silence between the enjambed word and the following word. In the current work, I sought to test Tsur's hypothesis while also taking into account the intrinsic and contextual factors that influence word and silence duration.

To assess the role of enjambment on production, I created a new data set which was limited to only words that occurred at Metric Level 3, as this was the only location where enjambment occurs in *The Cat in the Hat*. This smaller corpus included 2216 words, 1125 which were enjambed, and 1091 which were not. The word duration and inter-onset interval durations of the enjambed and non-enjambed words are presented in Figure 4. Using this subset of the corpus, I assessed the influence of enjambment on both word duration and post-word silence.



488

489 Figure 4: Values of word duration and post-word silence for enjambed and non-enjambed
 490 words occurring at Metric Level 3. Error bars indicate standard error.

491 3.3.1 Enjambment and word duration

492 The goal of the analysis was to investigate Tsur's (2012) claim that speakers signal
 493 discontinuity at locations of enjambment by increasing vowel (and subsequently, word)
 494 duration. Using the modeling method described above, I assessed whether enjambment
 495 predicted word duration over and above the other factors known to influence duration at
 496 Metric Level 3. The fixed factors in the initial model of Word Duration were Enjambment,
 497 Segment Number, Word Class, Lexical Frequency, Syntactic Structure, Text Emphasis, Inter-
 498 stanza repetition, and the interactions between Frequency/Word Class, and Syntactic

Structure/Word Class. The random slopes in the final model were Enjambment, Syntactic Structure, and Word Class, and the fixed effects in the final model are presented in Table 8.

Table 8

Fixed effects in the final model of word duration for Metric Level 3

	Metric Level 3: Word Duration		
	<i>B</i>	<i>std. Error</i>	<i>t-value</i>
Fixed effects			
(Intercept)	222.76	10.94	20.36
Enjambment	-13.54	6.90	-1.96
Segment Number	21.85	2.76	7.92
Word Class	47.19	7.95	5.94
Syntactic Structure	13.77	2.07	6.66
Word Class x Syntactic Structure	-5.02	1.96	-2.56

As in the prior models, both intrinsic and contextual factors predicted word durations at Metric Level 3: Longer durations were predicted by increases in Segment Number and Syntactic Structure as measured by LRB weight, and open-class words were produced with longer durations than closed-class words. Word Class interacted with Syntactic Structure such that open-class words were produced with consistently increasing duration as LRB weight increased, but closed-class words didn't show this systematic increase.

Critically, Enjambment was a marginally significant predictor of duration, $X^2(df = 1) = 3.59$, $p = 0.058$, such that enjambed words were produced with *shorter* durations than non-enjambed words, in contrast to Tsur's hypothesis. This result provides additional evidence that metric structure influences word durations above and beyond lexical and syntactic factors.

3.3.2 Enjambment and silence

To test Tsur's claim that speakers reduce silence after enjambed words, I modeled the duration of silence following words at Metric Level 3. The fixed factors in the initial model were Enjambment, Segment Number, Word Class, Lexical Frequency, Syntactic Structure, Text Emphasis, Inter-stanza repetition, and the interactions between Frequency and Words Class and between Syntactic Structure and Word Class. The random slopes in the final model were Text Emphasis and Repetition, and the fixed effects in the final model are presented in Table 9.

Table 9

Fixed effects in the final model of post-word silence for Metric Level 3

	Metric Level 3: Post-word Silence		
	<i>B</i>	<i>std. Error</i>	<i>t-value</i>
Fixed effects			
(Intercept)	180.80	30.75	5.88
Segment Number	-19.14	4.99	-3.84
Lexical Frequency	-10.11	2.01	-5.03
Syntactic Structure	18.62	1.85	10.09
Text Emphasis	67.04	19.76	3.39
Intra-stanza Repetition	35.15	14.73	2.39

Post-word silence at Metric Level 3 was predicted by both intrinsic and contextual factors. Similar to results from modeling of word duration and inter-onset interval, longer silences were predicted by decreases in lexical frequency, increases in Syntactic Structure as measured by LRB weight, and Text Emphasis. In contrast to results from the full corpus, longer silences at Metric Level 3 were predicted by *decreases* in both Segment Number and Intra-stanza Repetition (i.e., repeated words were followed by more silence than non-repeated words). Critically, although Enjambment led to a numerical reduction in post-word silence, it

was not a significant predictor of this effect in the final model, $X^2(df = 1) = 1.51, p = 0.22$.

This result, therefore, does not support Tsur's hypothesis that speakers reduce silence following enjambed words.

4 Discussion

In the current study, I investigated the role of metric structure in predicting duration in seventeen adult productions of Dr. Seuss's *The Cat in the Hat*. Regression modeling demonstrated that hierarchical metric structure accounts for word duration over and above other aspects of linguistic structure, including intrinsic factors Segment Length, Word Class, and Lexical Frequency, contextual factors Syntactic Structure, Text emphasis, and Intra-stanza repetition. However, the effects of the metric hierarchy differed depending on whether duration was operationalized as word duration only, or word duration plus any following silence. Specifically, the model based on word duration indicated that speakers realized three levels of metric hierarchy, and that rhyme targets were produced with numerically shorter durations than rhyme primes. Conversely, the model based on the sum of word duration and silence (i.e., inter-onset interval) revealed five levels of metric hierarchy where the interval between onsets of rhyme targets and the following word were significantly longer than those for rhyme primes.

The current results replicate prior findings that intrinsic factors like Segment Number, Lexical Frequency, and Word Class systematically influence speech production (e.g., Aylett & Turk, 2004; Bell, et al., 2009; Klatt, 1976), and that the effects of syntactic structure and frequency are larger for open-class words than closed-class words (Bell, et al., 2009; Segalowitz & Lane, 2000). Furthermore, these results replicate and extend prior work demonstrating the role of context on production durations. First, they replicate the finding that repetition leads to decreased production durations (Fowler & Housum, 1987;

Anderson & Howarth, 2002). Second, they provide the first demonstration that words presented in CAPS are produced with longer durations than the same words without such font emphasis.

The novel contribution of the current study is the demonstration that hierarchical metric structure accounts for variation in word duration and inter-onset interval over and above previously investigated factors, including both syntactic and prosodic structure. While prior work has demonstrated an influence of metric structure on short, repeated phrases (Cummins & Port, 1998), the current study is the first to demonstrate this influence for connected speech. Moreover, the similarity of the results observed in the current study to those from musical productions (Todd, 1985) provides further evidence of the similarities between musical and prosodic structure (e.g., Heffner & Slevc, 2015).

In addition to providing empirical support for the influence of metric structure on production, the current results further clarify the influence of syntactic structure and prosodic structure on production. Recall that in the current study syntactic structure was operationalized using the LRB model, which takes into account both syntactic structure and prosodic structure. The LRB instantiates syntactic structure by postulating increases in durational lengthening with increases in both the size of the syntactic constituent being completed and the size of the upcoming syntactic constituent (Breen, et al., 2011; Ferreira, 1991; Watson & Gibson, 2004). In addition, the model instantiates prosodic structure by disallowing phrase boundaries (i.e., durational lengthening) within phonological phrases, which are defined as content words and any preceding function words (see Table 2). The current results are the first demonstration of the success of the LRB model in accounting for production durations in a multi-sentence corpus, as previous investigations have been limited to single sentences.

However, the LRB is not the only existing model of production duration based on syntactic and prosodic structure. It is possible that another such model could account for the current results without recourse to metric structure. Other models have proposed that production durations (both word duration and post-word silence) are determined in part by speech planning processes, as influenced by syntactic structure, but also by timing constraints related to prosodic structure (*performance structures*; Gee & Grosjean, 1983). One such performance structure is a *bisection* constraint, reflecting speakers' tendency to produce phrase boundaries at locations that balance the size of the sentence material on either side of the boundary (Breen, et al., 2011; Fodor, 2002; Gee & Grosjean, 1983; Grosjean, Grosjean, & Lane, 1979). Indeed, in long enough sentences, bisection is argued to be hierarchical and iterative (Grosjean, et al., 1979). However, bisection has been discounted in subsequent work due to the fact that a) other syntactic and prosodic constraints can account for phrasing behavior without the need for a bisection constraint (Breen, et al., 2011; Gee & Grosjean, 1983), and b) the operation of a bisection constraint, particularly a hierarchical one, requires the speaker to have access to the entirety of the material that they will produce, which is at odds with our knowledge of the incrementality of language production (Ferreira, 1993).

The consistency of the metrical structure in *The Cat in the Hat* means that readers of this text, unlike the materials on which bisection algorithms have previously been assessed, *can* predict the metric and, to an extent, prosodic structure of the text. Therefore, while bisection has been deemed "epiphenomenal" in prose contexts (Gee & Grosjean, 1983), the current results demonstrate that when metric structure is highly predictable, and largely consistent with syntactic structure, speakers will implement hierarchical metric grouping in their productions, balancing the length of adjacent phrases, and increasing inter-onset intervals with increases in the hierarchical structure. However, the results also suggest that,

in cases where the speaker cannot predict upcoming metric and/or prosodic structure, as in most prose contexts, hierarchical metric structure will not influence production durations.

In addition to its strict hierarchical metric structure, *The Cat in the Hat* is defined by its consistent, predictable rhyming structure. The predictability of the rhyme targets in this corpus explains the dissociation between the effect of metric structure on word durations and inter-onset intervals: Although inter-onset intervals increased linearly with each increase in height in the metric hierarchy, resulting in a total of five distinct levels, word durations exhibited only three levels, and word durations did not differ among Metric Levels 3, 4, and 5. In this way, words associated with Metric Levels 4 and 5, which are always the rhyme prime and the rhyme target, are shortened relative to what would be predicted based on the inter-onset interval results. One explanation for this result is that speakers manipulate word durations based on predictability. Specifically, when a word is highly predictable in its context, it is shortened (Aylett & Turk, 2004; Bell, et al., 2009, Lieberman, 1963). Indeed, the final word of each stanza in the corpus (the rhyme target) is highly predictable based both on semantic context and, more importantly, phonological context. It is therefore likely that readers produced the rhyme targets with numerically shorter durations than rhyme primes due to the formers' high predictability. Under the *smooth signal redundancy hypothesis* (Aylett & Turk, 2004), this reduction is due to speakers' general strategy to distribute information uniformly in time across the speech signal.

An alternative explanation of the different pattern of results for word duration and inter-onset intervals is that distinct production pressures affect word durations and silences. Ferreira (1993, 2007) argues that word duration variation is predicted by prosodic structure, while silence is due to planning upcoming material. For example, Ferreira (1993)

demonstrated that word durations varied with syntactic structure, such that words were approximately 60% longer when they coincided with a syntactic phrase boundary (i.e., are phrase-final) than when they were phrase-medial. Post-word silences, on the other hand, were not influenced by previous sentence material; rather, they were determined by the size and complexity of upcoming sentence material. In this way, Ferreira's model can account for the word duration effects observed in the current study, particularly if the lack of difference between Metric Levels 3, 4, and 5 is interpreted as being due to a ceiling effect on single-syllable word durations. However, it is unlikely that readers have reached a limit on lengthening in the current study as prior investigations of child-directed speech demonstrate significantly longer production durations for similar words. For example, Ko & Soderstrom (2013) demonstrate that, in child-directed speech, single-syllable sentence-final words (e.g., ball, doll lawn, worm) are produced with average durations of 561 ms (SD = 139) for statements and 497 ms (SD = 124) for questions. As displayed in Figure 1, readers in the current study produced rhyme targets with an average duration of 361 ms (SD = 97), suggesting that they could lengthen rhyme targets significantly more than they did. Therefore, the lack of a difference in length between rhyme primes and rhyme targets is likely not due to a natural limit on lengthening for the targets.

Although I interpret the duration reduction of the rhyme targets to be an effect of the predictability of this word in its context, it is not clear what aspect of the communicative structure is driving this effect: whether it is a speaker effect or a listener effect. This example speaks to the larger debate about whether speakers reduce words due to their knowledge of listener comprehension, or due to production constraints. Under the *audience design* view, speakers reduce predictable words like the rhyme target because they know the word will be easily accessible for their listener (e.g., Galati & Brennan, 2010). On the other hand, speakers may reduce the rhyme target because it takes less effort for them to

655 produce a word that's been phonologically primed (as the rhyme target has been primed by
 656 the rhyme prime) (e.g., Bard, et al., 2000).

657 The challenge to distinguishing between an audience design and speaker facilitation view
 658 is that both positions make very similar predictions about patterns of reduction, and the
 659 current results cannot effectively differentiate between these alternative explanations.
 660 However, recent work demonstrates that speakers reduce targets when they know their
 661 addressee is anticipating the upcoming word (Arnold, Kahn, & Pancani, 2012). This result
 662 suggests that an individual speaker's reduction of rhyme targets in productions of *The Cat*
 663 *in the Hat* might vary depending on their knowledge of their listener's anticipation of the
 664 rhyme target. In the current study, there were no differences in duration reduction between
 665 participants who read the book out-loud to an audience of children and those who read the
 666 book alone in the lab. However, participants who read to an audience of children did not
 667 know the specific abilities of their audience, and therefore could not vary productions based
 668 on that knowledge. Future work could address this question by eliciting productions of *The*
 669 *Cat in the Hat* or other metrically regular texts from caretakers (e.g., parents) reading the
 670 book to their children. Under the hypothesis that speakers vary aspects of production based
 671 on knowledge of their interlocutors' linguistic knowledge, caretakers would be more likely
 672 to reduce the duration of rhyme targets that their children knew compared to targets they
 673 didn't know.

674 The results observed in the current study leave several open questions. First, to what extent
 675 are the observed results specific to child-directed speech, as opposed to a result of the text
 676 itself? Recall that speakers in the current study read the book in two different contexts –
 677 either to an audience of 4 and 5-yr-olds, or to no audience. Based on prior reports of
 678 prosodic enhancement in child-directed speech, specifically for phrasing and text emphasis

(Martin, et al., 2016; Church, et al., 2005; Ko & Soderstrom, 2013), I predicted larger durational effects for the productions with an audience; however, I observed no systematic differences between these sets of productions save for an increase in overall production duration for the productions to an audience. One reason for this lack of difference may be due to the between-subjects design and the variability of individual speakers. These differences might emerge more readily in a within-subjects design where individual speakers read the same text with and without an audience of children. Yet another reason for the lack of an effect is that the text itself, and the individual speakers' knowledge of it, lead all participants to read the book in a child-directed manner even when no audience was present. This alternate hypothesis is supported by a lack of difference in a prior investigation of perceived expressiveness between classroom and lab productions in the *Cat in the Hat* corpus (Breen, Weidman, & Guarino, 2014).

A second open question is to what extent hierarchical metric structure predicts durational variation in *non-rhyming* rhythmic text. The current results lead to the prediction that readers *would* similarly use word duration to signal metric structure. But it's likely that the simplicity of the syllabic and syntactic structure (and relative lack of enjambment), combined with the consistency of the rhyming structure in *The Cat in the Hat* make the consistent metric structure more salient to the reader. It's likely, therefore, that the effects of hierarchical metric structure will be weaker for non-rhyming texts than those observed here. Moreover, the results of the current study lead to the prediction that, in non-rhyming contexts, durations of stanza-final words will be significantly longer than words on the adjacent lower metric level.

The current study is part of a larger research program designed to determine whether exposure to rhythmic, rhyming books provides a cognitive benefit for learning readers.

Prior work demonstrates connections between children's appreciation of both rhythm and rhyme and their literacy development. For example, children's rhyming ability correlates with their phonological awareness and reading ability (Bradley & Bryant, 1983; McLean, Bryant, & Bradley, 1987). Evidence for the contribution of rhythmic skill to reading development comes from the observation of positive correlations between children's beat-tapping performance (i.e., ability to tap along with a metronome) and their reading abilities (Thomson & Goswami, 2008), and the finding that children's metric stress sensitivity (i.e., their ability to detect a mis-stressed word) explains variance in phonological awareness, rhyming ability, and word knowledge (Wood, 2006). These results suggest that facility with rhythmic, rhyming structures may enhance reading abilities for children.

It may be the case that the regular metric structure of these texts helps listeners attend better to the content they hear. Specifically, regular metric patterns allow listeners to make predictions about when in time upcoming information is going to occur (Huron, 2006; Fitzroy & Sanders, 2015). Moreover, adult listeners have been shown to exploit regular metric patterns as cues to speech segmentation (Mattys & Samuel, 1997), lexical organization (Breen, Dilley, McAuley, & Sanders, 2014), syntactic structure (Schmidt-Kassow & Kotz, 2009), and semantic structure (Rothermich, Schmidt-Kassow, & Kotz, 2012). One explanation for these effects, therefore, is that regular metric patterns direct listeners' temporal attention to important sentence material, thereby facilitating comprehension (Breen, et al., 2014; Pitt & Samuel, 1990; Quené & Port, 2005).

The claim that regular metric structure supports speech segmentation and word learning is supported by recent work exploring acoustic envelope patterns in infant-directed speech (Falk & Kello, 2017) and child-directed speech (Leong & Goswami, 2015). In a comparison of adult-directed and infant-directed speech and song, Falk & Kello (2017) demonstrated

that the same mothers produced infant-directed speech and song with more consistent hierarchical temporal structure than adult-directed speech and song, respectively, which may serve to enhance temporal salience as well as infants' engagement with the material. In a related finding, Leong & Goswami (2015) demonstrated that CDS emphasizes three amplitude modulations that correspond roughly to phoneme, syllable, and stress onsets, respectively. They argue that children could, in principle, track these modulations to extract hierarchical phonological structure from speech even in the absence of lexical knowledge. Indeed, their model accurately identified over 70% of phoneme onsets, syllable onsets, and prosodic stresses in a corpus of CDS comprised of common nursery rhymes with both duple and triple meters. These results suggests a possible mechanism by which productions of poetic CDS (like *The Cat in the Hat*) facilitates speech segmentation and phonological learning.

In summary, the effect of hierarchical metrical structure on production duration observed in the current study represents a previously unaccounted for source of variation and should be considered an important performance factor influencing speech production. That is, in metrically-regular linguistic constructions, as in metrically-regular musical constructions, word durations and inter-onset intervals increase linearly with position in a hierarchical metric tree. Future work will be directed to understanding the relationship between metric structure, predictability, and attention, to more fully explain the link between rhyming, rhythmically regular texts and reading ability. The present data indicate that readers of these books are providing more information about linguistic structure to their audience than previously known. This knowledge will help generate better-informed models of the relationship between language experience and reading skill.

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