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The Timecourse of Phonological Competition in Spoken Word Recognition: A Comparison of Adults and Very Young Children

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The Timecourse of Phonological Competition in Spoken Word Recognition: A Comparison of Adults and Very Young Children

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Abstract

Spoken word recognition (SWR) is the mapping of speech sounds to words from many potential candidates in one's lexicon. In adults, words that are phonetically similar, of high frequency, or semantically related compete for recognition. An ongoing debate in the literature is whether or not very young children encode spoken words with fine-grained temporal and phonetic detail. Specifically, whether they represent words wholistically or as smaller phonetic units similar to that of adults. The adult literature demonstrates that words that are phonetically similar at onset (cohorts) and offset (rhymes) compete for recognition. As it happens, rhymes have the potential to distinguish between developmental theories; some (wholistic-emergent) propose that children's early representations lack phonetic and temporal detail, and therefore global similarity should be the primary determinant of lexical competition, while other theories (accessibility) propose that rhyme competition should not emerge until after the onset of literacy acquisition (due either directly to phonological reorganization spurred by learning to read, or coincidental maturation). This study compared phonological competition effects of cohort and rhymes compared to unrelated words using a simplified visual world paradigm task. Typically developing preschool children (*n* = 23), ages 3-4, and college students (*n* = 22), ages 18-22, were presented with two pictures and followed a spoken instruction to click on one of them (e.g., "click on the doll"). Picture labels matched either onset (*bat-bath*), or offset (*keys-bees*), or were phonologically unrelated (*bear-pants*). Words were divided evenly between monosyllabic and bisyllabic words. Participants' eye movements were recorded as they followed the verbal instruction. Children were generally slower than adults at processing spoken words but showed competition patterns similar to those seen in adults. Both adults and children showed weaker rhyme effects and stronger cohort effects for monosyllabic words. These findings suggest that

rhyme competition emerges during pre-reading years, and also provides new insight into on-line lexical competition in adults and children.

Introduction

A typical adult can rapidly and accurately recognize approximately 42,000 words from memory with seemingly little overt effort (Brysbaert, Stevens, Mandera, & Keuleers, 2016). Many models of adult spoken word recognition (SWR) highlight the importance of temporal order of phonetic information (Marslen-Wilson, 1987; McClelland & Elman, 1986) for recognizing words from the lexicon. In general, theories of SWR agree that as a word is heard, multiple words are activated and compete for recognition. Degree of competition depends on factors such as phonetic similarity and the frequency of occurrence of each word (Luce & Pisoni, 1998; Kuperman & Van Dyle, 2013), though other factors may come into play, such as semantic relatedness (Rodd, Gaskell, & Marslen-Wilson, 2002). In the current study, theoretical concerns motivate a focus on two types of phonological competitors: words that overlap completely at onset (cohorts) or mismatch only at onset (rhymes). Previous research has demonstrated that both types compete for recognition as a function of phonetic similarity over time, but with stronger, earlier competition from cohorts than rhymes (Allopenna, Magnuson, & Tanenhaus, 1998). While much is known about the time course of processing spoken words in adults, less is known about how children recognize spoken words. Theories make conflicting predictions about the relative time course of cohort and rhyme competition in very young children, but to date, have not been assessed empirically. In the following section, I review evidence from the adult and developmental literatures that motivate an investigation of these two types of potential competitors in young children's spoken word recognition.

Timecourse of Adult Spoken Word Recognition

Given the temporal nature of the speech signal, models of spoken word perception suggest that as an individual hears a word, similar words in memory are activated incrementally as the word is heard and compete for recognition (Marslen-Wilson, 1987; McClelland & Elman, 1986). For example, words that start with the phoneme /b/ will activate all words that start with that sound (e.g., *beach*, *big*, *bulge*, *baste*). As additional information from the speech stream is processed, some potential candidates are strengthened while others are attenuated. For example, if the next phoneme is /i/, then *beach*, *beam*, *bee*, and *believe* all become strengthened while *big*, *bulge* and *baste* are attenuated. According to the Cohort Model, this process continues until a single candidate word remains, or until the "current" phoneme cannot be added to a previous series, revealing a word boundary (Cutler, 1995; Marslen-Wilson & Welch, 1978). While the Cohort Model posits that only words that are very similar at onset are activated, the Neighborhood Activation Model (NAM; Luce, 1986; Luce & Pisoni, 1998) proposes that words that are sufficiently globally similar are activated. Specifically, on NAM's "DAS" rule, words differing by no more than a single phoneme deletion, addition, or substitution are neighbors and compete for recognition. A word's neighborhood includes cohorts only if they differ by no more than one phoneme (*beach*'s neighbors include *bee* and *beam*, but not *believe*), but also words that mismatch at onset that would be excluded from the Cohort model competitor set (*beach*'s neighbors also include *reach* and *leech*). The TRACE model (McClelland & Elman, 1986) makes an intermediate prediction: words that overlap at onset are strongly activated because of their early overlap; because activated words inhibit other words, words that mismatch at onset but are highly similar to the target word later (e.g., rhymes) are activated more strongly than unrelated words, but less strongly than words overlapping at onset. Allopenna, Magnuson and

Tanenhaus (1998) found strong support for the TRACE predictions in adults using the visual world paradigm (VWP; Tanenhaus et al., 1995): onset competitors ("cohorts") competed early and strongly, while rhymes competed more weakly and later. These results highlight two primary factors that govern competition in adult spoken word recognition: overall similarity and temporal order. The greater the phonetic similarity between two words, the greater the competition effect, but early overlap yields greater competition than late overlap.

The Development of Spoken Word Recognition

The developmental literature examining children's SWR abilities can be divided into two somewhat divergent theories. The first, often referred to as the w*holistic-emergent view* (Walley, 2003), has been hypothesized to be a protracted process of gradual refinement through age seven (Fowler, 1991). This view posits that children initially process words in a wholistic manner and that lexical representations are underspecified in terms of phonetic information, based on evidence that early in development, children pay minimal attention to detail or sequence of phonemic information (Walley, 2003). On this view, lexical representations become more refined over the course of development in that children's representations contain detailed phonetic and temporal information similar to that of adults (Treiman & Baron, 1981). An alternative theory, the *accessibility view*, posits that children's lexical representations are differentiated to include segmental and fine-grained information from a very young age; however, this information is not metalinguistically accessible until exposure to reading instruction and the development of metacognitive abilities (Liberman, Shankweiler & Liberman, 1989).

The wholistic-emergentist view. Several experiments by Treiman and Breaux (1982)

provide empirical support to the wholistic-emergent processing theory. In their experiments, they compared adult and preschool children's classification of spoken syllables. One possible way to group the syllables was based on a common phoneme (e.g., grouping /bɪs/ and /bun/ together based on the initial phoneme /b/) while the other possible method was based on overall similarity (e.g., grouping /bɪs/ and /diz/ together because all phonemes in each position were phonetically similar). The preschool children grouped the overall similar syllables more easily than those that only shared a single phoneme, suggesting a more wholistic processing of syllabic units. Additional support for this theory is provided by Elliott, Hammer and Evan (1987). These researchers utilized a forward-gating procedure in which first graders, high school adolescents and older adults heard successively longer portions (gates) of a given word across trials. They found that the youngest group of participants required significantly more information from the speech signal before recognizing even the most familiar words. Interestingly, in a study that replaced or added noise to a word segment, adults rated the stimuli as noisier when the noise was found in the initial segment, but five-year-old participants did not. These results highlight the priority adults give to onset segments of a word, and suggest children's early word representations may encode sequential information less precisely.

This type of whole-unit processing is postulated to gradually shift to precise, adult-like encoding during the early school years. This emergent theory is developmentally plausible, as one of the primary goals for very young children is to recognize and produce a small repertoire of whole words; depending on the content of the early lexicon, distinguishing among its words may not require precise sequence or phonetic encoding (Gerken, Murphy, & Aslin, 1995). During the rapid vocabulary growth observed in childhood that starts around two years of age, it has been suggested that words begin to be represented segmentally to allow efficient storage and

retrieval from memory (Jusczyk, 1986). It is posited that as the contents of the lexicon expand, pressure increases to encode temporal order and phonetic detail (Gerken et al., 1995), and a young child's ability to decompose words into syllables and intrasyllalble units (onset, rimes) emerges (Fowler, 1991; Treiman & Zukowski, 1991). This phonological reorganization includes the emergence of *phonological sensitivity*, the awareness that words are comprised of smaller units (e.g., phonemes) and that the units can be manipulated in rule-governed ways. These phonological skills have been associated with both oral language development (de Jong, 2000; Gathercole & Baddeley, 1993) and early reading achievement (Anthony et al., 2002). Others have postulated the explicit awareness of segmental information within words develops as children begin to learn to read (Liberman & Shankweiler, 1985).

Interestingly, this wholistic processing is observed in other cognitive and perceptual domains, including attention and vision, in which young children process input *integrally,* as undifferentiated wholes (Aslin & Smith, 1988; Shepp, 1978). Children less than six years of age perform better on tasks that necessitate attention to the whole as opposed to constituent parts (Kemler, 1983). Using a timed card-sorting task, first graders demonstrated difficulty attending to and utilizing a single dimension to sort the cards whereas sixth graders completed the task with ease (Shepp & Swartz, 1976). Smith and Kemler (1977) demonstrated similar findings with kindergarteners, second graders and fifth graders on classifications of stimuli that varied in size and brightness. The youngest participants used both dimensions, size and brightness, to group objects whereas the oldest participants grouped stimuli from each dimension separately. Vurpillot (1968) utilized an embedded figure task to evaluate part-whole processing of visual information in both younger and older children. Specifically, children were given pairs of line drawings of houses that were either the same or different. The pairs that differed were dissimilar

based on their window properties. Some windows had curtains, while others had shutters and the remainder had objects on their ledge. The young children demonstrated difficulty disembedding smaller, simple shapes (the windows) from the gestalt (the house) whereas the older children easily identified the whole shape and the embedded shapes within the gestalt. However, it is important to note that auditory information is temporally sequential and requires storage in memory whereas visual information does not share these properties making direct comparison between the two modalities challenging.

The accessibility view. Findings from studies examining phonological competition provide compelling evidence to the support the notion that even very young children do in fact attend to temporal order, in conflict to wholistic-emergent theory. The *accessibility view* of word recognition postulates that children's early representations do contain phonetic detail including segmental and phonemic information, but young children do not have explicit access to this level of information until the emergence of metacognition and direct reading instruction (Morais, Bertelson, Carey & Alegria, 1986). Evidence to support this theory can be derived from studies of infants, school-age children and individuals with dyslexia.

Swingley, Pinto and Fernald (1999) presented 24-month-olds with visual displays while listening to a sentence that contained a target word from one of the two displays. An increased latency in response was observed when the competitor distractor picture had the same onset (e.g., dog vs. doll) but not when the competitor rhymed (e.g., cat vs. hat). These findings appear incompatible with the theory of wholistic processing, where global similarity (rather than order of similarity, i.e., early vs. late) should predict competition.

A series of infant studies provide evidence to support detailed lexical representations as young as the first year of life. In one (Swingley & Aslin, 2002), 14-month old infants were

shown two pictures while hearing a sentence with a correctly pronounced word (e.g., baby) or an incorrectly pronounced word (e.g., vaby). One of the pictures contained the intended referent (e.g., baby). Eye movement data revealed that the infants were slower at recognizing the referent when the target word was mispronounced. However, these findings could also account for the wholistic-emergentist view since mismatch was only presented for word onset. These findings suggest that even very young children are sensitive to some detail despite the fact that attention to these differences may not necessarily be useful in spoken word recognition (Swingley & Aslin, 2002; Swingley & Aslin, 2000). Relatedly, infants as young as 19 months of age have demonstrated graded sensitivity when provided with auditory stimuli varying on a continuum of acoustic features (White & Morgan, 2008).

Studies of school-age children also support the accessibility view in that a surge in phonological sensitivity is observed around the time a child begins formal reading instruction, as demonstrated by performance on phonological awareness tasks. Phonological awareness, also referred to as phonological sensitivity, describes to the ability to identify and manipulate sounds units within a word (de Jong, Seveke, & Van Veen, 2000). These skills have been shown to develop in a hierarchical manner, with children demonstrating sensitivity to lower level, larger and less complex linguistic units such as words and syllables before they are sensitive to higher level units such as phonemes (Anthony et al., 2002). Studies comparing preschool children (ages 3-4) and children enrolled in kindergarten (ages 5-6) demonstrated significantly different performance on segmenting tasks. The preschool children who had yet to receive reading instruction performed more poorly than kindergarten children on segmenting words into

phonemes, onsets or rimes (nucleus and offset of a syllable[1]; Seymour & Evans, 1994). Interestingly, the development of phonological awareness at around the time of reading instruction has been shown across many languages including Greek, Turkish, French and English, despite vastly different phonological structures between these languages (Ziegler & Goswami, 2005).

Special Populations and Word Perception

Children with developmental dyslexia and adults who are not literate provide additional insight into word processing, supporting the hypothesis that there may be cognitive prerequisites, specifically, phonological awareness and reading, that play a critical role in the timecourse of SWR. Desroches, Joanisse, and Robertson (2006) conducted a study in which typically developing children and children with developmental dyslexia, 8 to 10 years of age, completed a phonological awareness task (e.g., initial sound judgement and rhyme judgement) and a VWP task while their eye movements were tracked. Children heard a target word which appeared on a display (e.g., candle), along with an onset competitor (e.g., candy) or a rhyme competitor (e.g., sandal). While those with dyslexia demonstrated slower recognition of the targets when an onset competitor was present, similar to those children without dyslexia, they failed to show this attenuated recognition in the presence of a rhyme competitor. The children with dyslexia also

[1] The reader may have noticed the use of two terms that one might assume should be synonyms: rhyme and rime. *Rime* is the technical term for the nucleus and offset of a syllable (e.g., "each" from *each*, *beach*, or *breach*). Monosyllabic words *rhyme* when they share a rime (*strong*, *long*). Rhyme contrasts with rime when we consider multisyllabic words; we define multisyllabic rhymes as words that differ only in word onset (*beaker-speaker*, *handle-sandal*). Note that this differs from poetic rhymes in English, where what matters is sharing of a final strong rime (e.g., *beaker-ticker* are not poetic rhymes, but *balloon*'s poetic rhymes include *cartoon*, *teaspoon*, *macaroon*, *prune* and *moon*). Thus, we use the more general term, **rhyme**, to include multisyllabic pairs such as *beaker-speaker* as well as monosyllabic pairs such as *strong-long*.

performed more poorly than peers on the phonological awareness task. These findings imply that either phonological awareness, reading skills or both may impact the nuances of word perception. However, it is important to remember that those with developmental dyslexia may also have concomitant oral language disorders that may confound study results.

An alternative method of studying the impact of phonological awareness and reading on word perception may be to utilize typically developing adults who were never provided with formal reading instruction. Morais and colleagues (1986) designed a study that compared the effect of literacy training on speech segmentation skills with illiterate and formerly-illiterate adults (that is, individuals who learned to read as adults, whom Morais et al. referred to as "ex-illiterate adults"). The illiterate group never received formal reading instruction, the ex-illiterate adults began reading instruction between the ages of 18 to 40 years. The illiterate adults performed more poorly on phoneme deletion tasks, specifically deleting the initial consonant of a word (e.g., in English, an example would be "say *CAT* without the /k/") compared to the ex-illiterate adults. These same illiterate adults were also unable to perceive phonetic segments in a detection task while ex-illiterate adults were able to perceive these segments. Lastly, the adults who were illiterate also performed more poorly on rhyme detection tasks compared to those later-reading adults. These findings, in addition to the findings observed in developmental dyslexia, appear to support a relationship between phonological awareness and learning to read.

Distinguishing the Wholistic-emergentist and Accessibility Views

Despite evidence supporting both the emergent and accessibility views on lexical processing in children and the underlying phonological representations that support these skills, it seems that the truth lies somewhere between the two. For example, the emergent theory fails to account for

the fact that even very young infants, before the first full year of life, do in fact perceive small phonetic differences as evidenced by performance on categorical perception tasks (e.g., Juscyzk, 1987) and can perform very rudimentary segmentation tasks by identifying familiar words from an ongoing speech stream (Jusczyk & Aslin, 1995). These tasks, while very basic, appear to support the idea that a segmental foundation (both in terms of phonetic detail and sequential order) for word perception is present very early in development.

In the same vein, the accessibility view fails to account for interactions between phonological encoding and reading development. Interestingly, changes in word perception have been observed through adolescence. For example, findings from the VWP and eye movement studies have found that older children (adolescents) are faster at processing spoken words compared to younger (9-year-old) children (Rigler, Farris-Trimble, Greiner, Walker, Tomblin & McMurry, 2015). The 9-year-old children also demonstrated greater competition from phonologically similar words compared to the 16-year-old children in the same study. It is possible that other developmental changes that occur during childhood could account for differences in word recognition skills. For example, as Rigler et al. (2015) discuss, executive control, which continues to develop well into early adulthood, has been posited to affect word recognition, in particular inhibitory control. It is possible that controlled, top-down inhibition may be involved in the attenuation of lexical competitors although work on this remains ongoing.

Apparent wholistic-to-incremental shifts in adults and computational models

Magnuson, Tanenhaus, Aslin, and Dahan (2003) trained adults to recognize novel words using an artificial lexicon task. The novel words formed small neighborhoods where each word had

one onset neighbor (i.e., a cohort) and one rhyme neighbor. For example, in the set /pibo/, /pibu/, /dibo/, /dibu/, the competitors for /pibo/ are /pibu/ and /dibo/. Adults appeared to exhibit a shift from a more wholistic mode of processing to a more incremental one: early in training, there was similar competition (early and strong) for rhymes and cohorts, but as training progressed, competition became more incremental, with earlier, stronger cohort effects and later, weaker, rhyme effects, resembling the pattern previously observed with familiar words (Allopenna et al., 1998).

Magnuson et al. used simulations with a simple recurrent network (SRN) in an effort to better understand these findings. The SRN was trained on analogs of the same artificial lexical items. The SRN exhibited the same apparent wholistic-to-incremental shift, with equivalent cohort and rhyme competition early in training, and early, strong cohort and late, weak rhyme effects after substantial training. However, Magnuson et al. also noted that, even in the early stages of SRN training, there was evidence for incremental processing, in that cohort effects led rhyme effects slightly. While this subtle detail was not observed in the human performance data, complications of the design (e.g., a crossing of target and competitor frequency) could have masked it in the overall data presented by Magnuson et al. (in their Figure 2).

Magnuson et al. speculated that wholistic-to-incremental shifts could be illusory side-effects of the transition from weakly- to strongly-learned representations. When representations are weak, their relative activations will be similar (just as in the earliest milliseconds of SWR, frequency effects are difficult to detect because the bottom-up input is not yet strong enough to drive large differences in activation; Dahan, Magnuson, & Tanenhaus, 2001). This could result in apparently similar levels of cohort and rhyme competition, even though the system is sensitive to temporal order.

The reason this remains an open question is that the crucial experiments required to compare cohort and rhyme effects in adults and children directly have not been conducted. This project aims to being to fill this gap.

Experiment

This project will use the VWP to assess rhyme sensitivity in preschool children and adults. Any potential outcome – whether preschool children fail to demonstrate rhyme sensitivity, demonstrate less rhyme sensitivity than adults, or demonstrate adult-like rhyme sensitivity – would have important theoretical implications. If preschool children fail to show rhyme sensitivity, this would motivate crucial questions about the process and developmental emergence of rhyme competition, such as whether it represents phonological reorganization as a by-product of learning to read, or other as-yet unspecified maturational processes. If preschool children demonstrate rhyme sensitivity in the VWP, this would challenge theories that posit early wholistic processing or that explicit reading instruction is required to perceive rhyme structure.

Methods

Participants

Child and adult participants were recruited through different means. Adult participants were recruited via the University of Connecticut Psychological Sciences Participant Pool while child participants were recruited through community resources, specifically public and private preschool programs. The University of Connecticut's Institutional Review Board approved the study protocol prior to the start of recruitment.

Participants were recruited from two age groups: (1) Adult readers, ages 18-23 years who were fluent readers; and (2) Pre-reading preschool children, ages 3-5 years. A total of 22 adult

participants and 23 preschool participants completed study procedures. See Table 1 for participant characterization.

Table 1

Participant Characterization.

	Group	
	Preschool (*n* = 23)	Adult (*n* = 22)
% Female	60.87%	72.72%
Mean Age in Years (*SD*)	4.19 (1.01)	19.15 (1.08)
Mean TOWRE-2 Index Standard Score (*SD*)	-	107.05 (8.21)
Mean TOPEL Print Knowledge Standard Score	109.43 (13.06)	-

Note. Standardized measures have a mean of 100 and standard deviation of 15.

Inclusionary/exclusionary criteria. All child and adult participants were native English speakers with no reported history of speech and language delays, hearing impairments or special education services. All participants had adequate visual acuity to complete tasks based on self or parental report. Participants in the adult group were fluent readers as measured by average index score on the Test of Word Reading Efficiency – Second Edition (TOWRE-2; Torgesen, Wagner, & Rashotte, 2012). All participants in the preschool group were not yet reading as measured by the Test of Preschool Early Literacy Print Knowledge subtest (TOPEL; Lonigan, Wagner, Torgesen, & Rashotte, 2007. The Print Knowledge subtest assessed early knowledge of written language, the skills necessary to read, including understanding aspects of print, letter identification and naming, and sound-letter correspondence. All child participants included in this study failed to answer a subset of these items and thus were clinically judged to be pre-readers.

Materials

Each participant completed an adapted version of a visual world paradigm task (Allopenna et al., 1998) in which two photographs appeared on a computer screen and a target

word embedded in a simple auditory instruction (*"Find the coat*") was presented via headphones.

Auditory stimuli were 108 mono and bisyllabic words following the carrier phase "*find the*" spoken by a native English speaking male using child-directed speech. Stimuli were recorded via omnidirectional microphone connected to a preamplifier and saved directly to a hard drive using PRAAT software (Version 6.0.10). The average length of the carrier phrase was 848 ms (*SD* = 86 ms) and the average length of the target word was 806 ms (*SD* = 105).

Auditory stimuli were divided into three conditions based on their phonological properties. Each condition had 18 word pairs for a total of 54 pairs. The Cohort and Rhyme conditions contained phonologically related word pairs. Cohort pairs had the same onset (e.g., same initial consonant-vowel (CV) combination for monosyllable pairs or same initial syllable for bisyllabic words) while Rhyme pairs had the same offset (e.g., same final CV or VC for both mono and bisyllabic words). The Unrelated condition contained word pairs that were phonologically unrelated (e.g., *bird-sock*).

Word pairs were divided into two Lists, A and B; in List A one word in the pair was designated as the target (e.g., for *coat-comb, coat* would be the target), while in List B the other (e.g., *comb)* would be the target. The same was done for unrelated items, such that for *bear-pants, bear* was the target in one list, and *pants* was the target in the other. Lists were matched for word frequency and phonotactic properties (see details below). Word pairs were split into lists to diminish the likelihood of inadvertent order contingencies and to safeguard against participants becoming aware, whether explicitly or implicitly, of the experimental manipulations. Trials were pseudorandomized for each list so that there were never two consecutive Cohort or Rhyme trials. Each list had two unique pseudorandomizations for a total of four lists (A1, A2, B1, B2).

Target words utilized in the experiment were derived from the MacArthur-Bates Communicative Development Inventories (MB-CDI; Fenson et al., 2007) and other studies of preschool language (Bryant et al., 1990; De Cara & Goswami, 2003) to ensure participants were familiar with the target word. Specifically, words that at least 80% of children produce by age 30 months were selected from the MB-CDI (Frank, Braginsky, &Yurovsky, 2016). Of the 108 target words used for the experiment, 96 were obtained from the MB-CDI. However, to ensure an adequate number of rhyming word pairs, other sources for target words were used including published studies of preschool language. Mean log word frequency was balanced between each condition and list using data derived from the SUBTLEXus database. Mean biphone probability was calculated as outlined by Vitevitch and Luce (1998) and also balanced between each condition and list using the Kucera and Francis (1967) database. For each word, a prototypical photograph appropriate for young children was chosen. Each photograph was edited and placed on a white background.

Table 2

Word Frequency and Phonotactic Properties of Real Word Stimuli by Condition.

Condition	Mean Log Word Frequency	Mean # Cohorts (*SD*)	Mean # Neighbors (*SD*)	Mean Segment Probability (*SD*)	Mean Biphone Probability (*SD*)
Unrelated	3.08 (0.62)	100.17 (95.72)	11.89* (14.23)	0.05 (0.01)	0.004 (0.003)
Cohort	3.08 (0.54)	90.71 (67.63)	18.66 (17.29)	0.06 (0.01)	0.005 (0.003)
Rhyme	3.04 (0.84)	129.75 (129.37)	21.61 (17.34)	0.06 (0.02)	0.006 (0.004)

Note. Mean Log Word Frequency was derived from the SUBTLEXus data. Phonotactic probability for words were derived using methods outlined by Vitevitch and Luce (1998) using Kucera and Francis (1967) database. **Targets selected for the unrelated condition have a smaller number of phonological neighbors compared to Cohort and Rhyme condition; however, this is not a confound with phonological condition, since its effect would be in the opposite direction. That is, the prediction is that targets in the unrelated condition should be*

fixated more quickly than targets in the cohort or rhyme conditions. However, words that have more neighbors are fixated more slowly in the VWP even when none of those neighbors are displayed (Magnuson et al., 2007). Thus, we have decided to accept this minor difference given the difficulty in finding items that are highly imageable and equated on as many of these dimensions as possible.

Experimental Task

For each trial, participants were presented with a 500 ms preview of two images, corresponding to target and the potential competitor. After the preview, participants were presented with the auditory instruction (e.g., "*find the coat*") and used the computer mouse to click on the target image. The trial ended once the participant clicked on an image (see Figure 1). Each participant completed 54 trials, consisting of 18 Cohort trials, 18 Rhyme trials and 18 Unrelated trials, with 9 monosyllabic trials and 9 bisyllabic trials in each condition. Trial order was pseudorandomized as described in the materials sections. Target and competitor image locations were balanced so half the target images appeared on the left side of the screen.

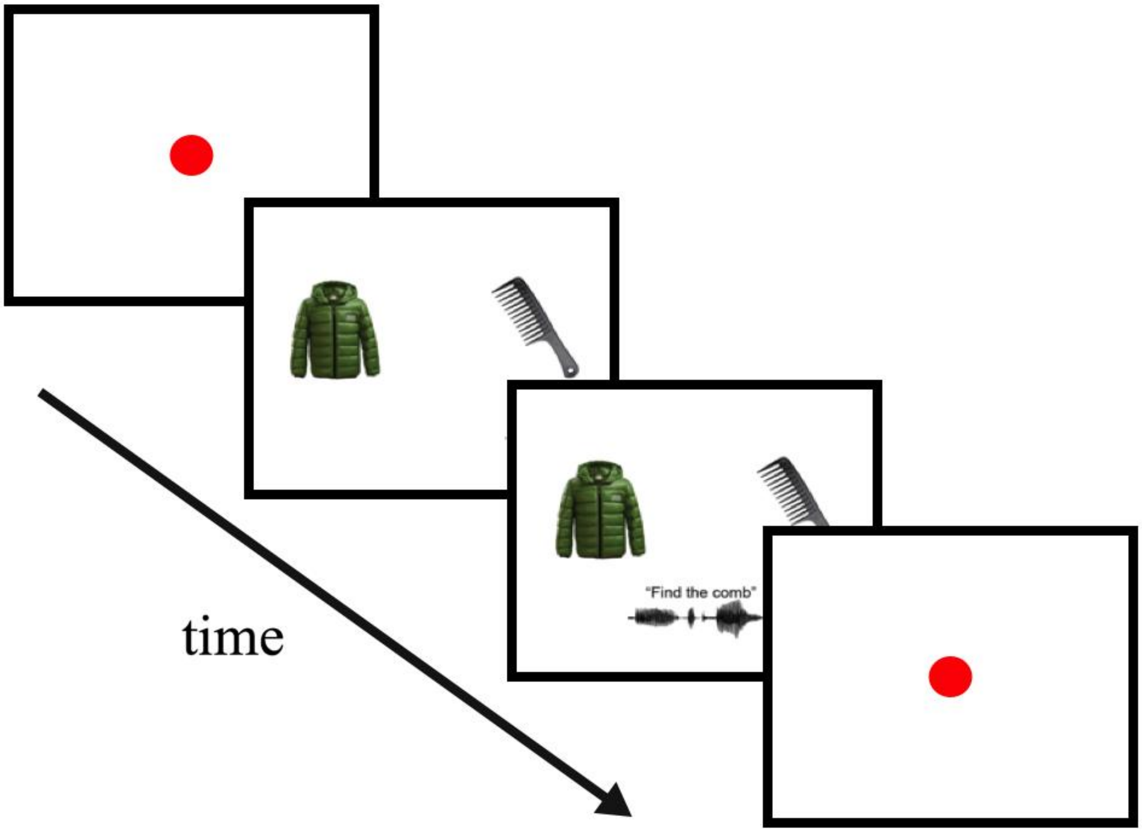


Figure 1. Presentation of stimulus.

Post-Experiment Object Labeling Test

The preschool group completed a brief post-test after they finished the eye tracking task to evaluate their knowledge of the photographs presented during the experiment. This was to ensure that our experiment was not simply a measure of vocabulary and that each child had adequate knowledge of each target and distractor – a precondition for competition. The labeling test was presented after the experimental task so as not to contaminate it, while allowing for the possibility of, e.g., removing specific trials for individual children based on their knowledge. Each target image was presented on a computer screen (in random order) and the participant was asked to name the object. If the participant responded correctly, the examiner moved to the next

image. If the participant responded incorrectly, the examiner asked if the object could have another name. If the participant failed to provide the correct name, the experimenter provided the correct label and moved to the next item.

Eye Movements

Participants' eye movements were captured using an EyeLink 1000 remote eye tracker (SR-Research Ltd.). Eye position was sampled at 500 Hz. Gaze recording began upon presentation of the two images and continued until the participant clicked either image with the computer mouse. Data Viewer software (SR-Research Ltd.) was utilized to preprocess gaze data. Fixation locations were coded as fixations to the target, the distractor/competitor or "other" (any other position, including the central fixation point). These fixations were then put into 50 ms bins for the duration of the target word to obtain the mean fixation proportion for each object during the target word for each trial.

Predictions

We predict that that our child participants will demonstrate robust cohort and weaker rhyme effects similar to results from previous work on phonological competition in adults (Magnuson et al., 2003; Allopenna et al., 1998). This prediction is driven by recent infant and toddler literature supporting the presence of phonological sensitivity in very young children (see Swingley & Aslin, 2000, 2002; White & Morgan, 2008). However, it is possible that rhyme effects may be attenuated in some way since our preschool group has not yet learned to read. This prediction is motivated by the work on children with developmental dyslexia (Desroches et al., 2006) and “ex-illiterate” adults (Morais, 1986).

The syllable condition was not a theoretically-motivated manipulation, but one that emerged to ensure an adequate number of experimental items. However, the following exploratory predictions can be considered. Phonological competition occurs when a listener hears phonologically related words. Strength of competition arises from the amount of phonetic overlap between the words heard (Luce & Pisoni, 1998). We might expect that the differences between the amount of phonetic overlap between monosyllabic and bisyllabic words would impact competition effects. Word pairs with greater phonetic overlap may compete more strongly than words with less phonetic overlap.

Results

Participant groups were analyzed separately due to large developmental differences between the preschool and adult groups. Initial inspection of the data showed that the young participants required more time to complete each experimental trial. As we shall see below, this translated into over-time fixation behavior on qualitatively different time scales, making direct comparison difficult. Additionally, given the disparities in the cognitive skills between groups, direct comparisons between the preschool children and adults would likely be challenging to interpret.

Growth curve analysis (GCA; Magnuson, Dixon, Tanenhaus, & Aslin, 2007; Mirman, 2014; Mirman, Dixon, & Magnuson, 2008) was used to evaluate the effects of Phonological condition and Syllable condition on the mean proportion of fixations to the target object utilizing a 1000 ms analysis window from 0 ms to 1000 ms after word onset. An analysis window of 1000 ms based on the literature (e.g., Mirman, Dixon, & Magnuson, 2008) and visual inspection of differences in timing that might motivate the time analysis window. Analysis of targets instead of competitors was on the small body of literature of phonological competition in school-age children (Desroches et al., 2006). Three separate models were conducted for each participant

group, in order to provide easily interpretable assessments of main effects of phonological competitor type as well as number of syllables to complement a fully-crossed model. In each model, treatment coding was used, such that effects are evaluated as change from a baseline, as we describe next.

For Model 1, the average fixation time course was modeled using third-order orthogonal polynomials and fixed effects of Phonological condition (Cohort, Rhyme, Unrelated; within-participant). The Unrelated condition was used as the baseline and parameters were estimated for how Cohort and Rhyme conditions differed from that baseline. Participant was included as a random variable, including random intercepts. This provides us an analog to the main effects of phonological type in ANOVA.

In Model 2, the average fixation time course was modeled using third-order orthogonal polynomials and fixed effects of Syllable condition (Monosyllabic, Bisyllabic; within-participant), again yielding similar results to that of the main effects of ANOVA. The Monosyllabic condition was used as the baseline and parameters were estimated for the Bisyllabic condition. Participant was included as a random variable, including random intercepts.

Model 3 is the fully-crossed model where the average fixation time course was modeled using third-order orthogonal polynomials and fixed effects of Phonological condition (Cohort, Rhyme, Unrelated; within-participant) and Syllable condition (Monosyllabic, Bisyllabic; within-participant) on all time terms. The three terms were included in the model given the shape of fixation proportions over time observed in previous eye tracking studies of phonological competition (Magnuson et al., 2007). The baseline was the Unrelated x Monosyllabic condition. Effects of competitor type (Cohort, Rhyme) were evaluated as difference from the baseline (hence, the effect of Cohort describes the changes required in growth curve parameters to model

the Cohort x Monosyllabic condition relative to the Unrelated x Monosyllabic baseline). The effect of syllable was evaluated as the changes needed from the baseline (Unrelated x Monosyllabic) to model the Unrelated x Bisyllabic condition. Interactions evaluate how growth curve parameters must additionally change to fit the Cohort x Bisyllabic and Rhyme x Bisyllabic combinations. Participant was included as a random variable, including random intercepts.

Contra prescriptions to "keep it maximal" (Barr, Levy, Scheepers, & Tily, 2013) in terms of random effects structure, we did not include by-participant random quadratic or cubic terms because we do not have sufficient degrees of freedom with the current enrollment (only ~5 participants per cell due to the constraints on counterbalancing) to support the maximal structure (more participants will be enrolled). Similarly, we did not compare Cohort x Rhyme due to small sample size. All analyses were completed in RStudio (Version 1.0.143) using the lme4 package (1.1-10) for multilevel modeling.

Trial Accuracy and Reaction Times

Trials in which the participants failed to click on the correct target image were excluded from eyetracking and reaction time analyses. The adult group responded incorrectly to 8% of monosyllabic cohort trials, 1% of the bisyllabic cohort trials and < 1% of bisyllabic rhyme trials with no other errors in the remaining conditions (see Table 3). A 3 x 2 factorial ANOVA revealed a significant main effect of phonological condition, $F(2, 126) = 19.36$, $p < .001$ and syllable level $F(1, 126) = 10.66$, $p < .01$ on trial exclusion. Cohort trials were significantly more likely to be eliminated compared to Rhyme and Unrelated. Monosyllabic trials were also significantly more likely to be eliminated compared to Bisyllabic trials. Pairwise comparisons revealed no difference in trial elimination between Rhyme and Unrelated trials. There was also a

significant phonological by syllable interaction, $F(2, 126) = 13.36$, $p < .001$ indicating that bisyllabic cohort trials were more likely to be eliminated from analysis compared to monosyllabic Rhyme and Unrelated trials.

The preschool group responded incorrectly to approximately 15% of cohort trials, 8% of rhyme trials, and 7% of unrelated trials at the monosyllabic level. For the bisyllabic trials, approximately 8% of cohort trials, 7% of rhyme trials and 5% of unrelated trials were incorrect and subsequently eliminated from analysis. A 3 x 2 factorial ANOVA failed to reveal significant differences of phonological condition ($p = .08$) or syllable level ($p = .16$).

Mean reaction time in milliseconds for each trial from onset of target word to mouse click on target picture were calculated by group, phonological type and syllable level and are reported in Table 3 below.

Table 3

Mean Trial Accuracy and RTs by Syllable Level and Phonological Condition by Participant Group

	Monosyllabic			Bisyllabic		
	Cohort	Rhyme	Unrelated	Cohort	Rhyme	Unrelated
# trials correct						
Adults	8	9	9	9	8	9
Preschoolers	7	8	8	8	8	8
Proportion of trials excluded						
Adults	8%	0%	0%	1%	0.5%	0%
Preschoolers	15%	8%	7%	8%	7%	5%
RT in ms (*SD)*						
Adults	2116	1897	1859	1895	1948	1867
Preschoolers	4277	4359	4120	3929	4180	4142

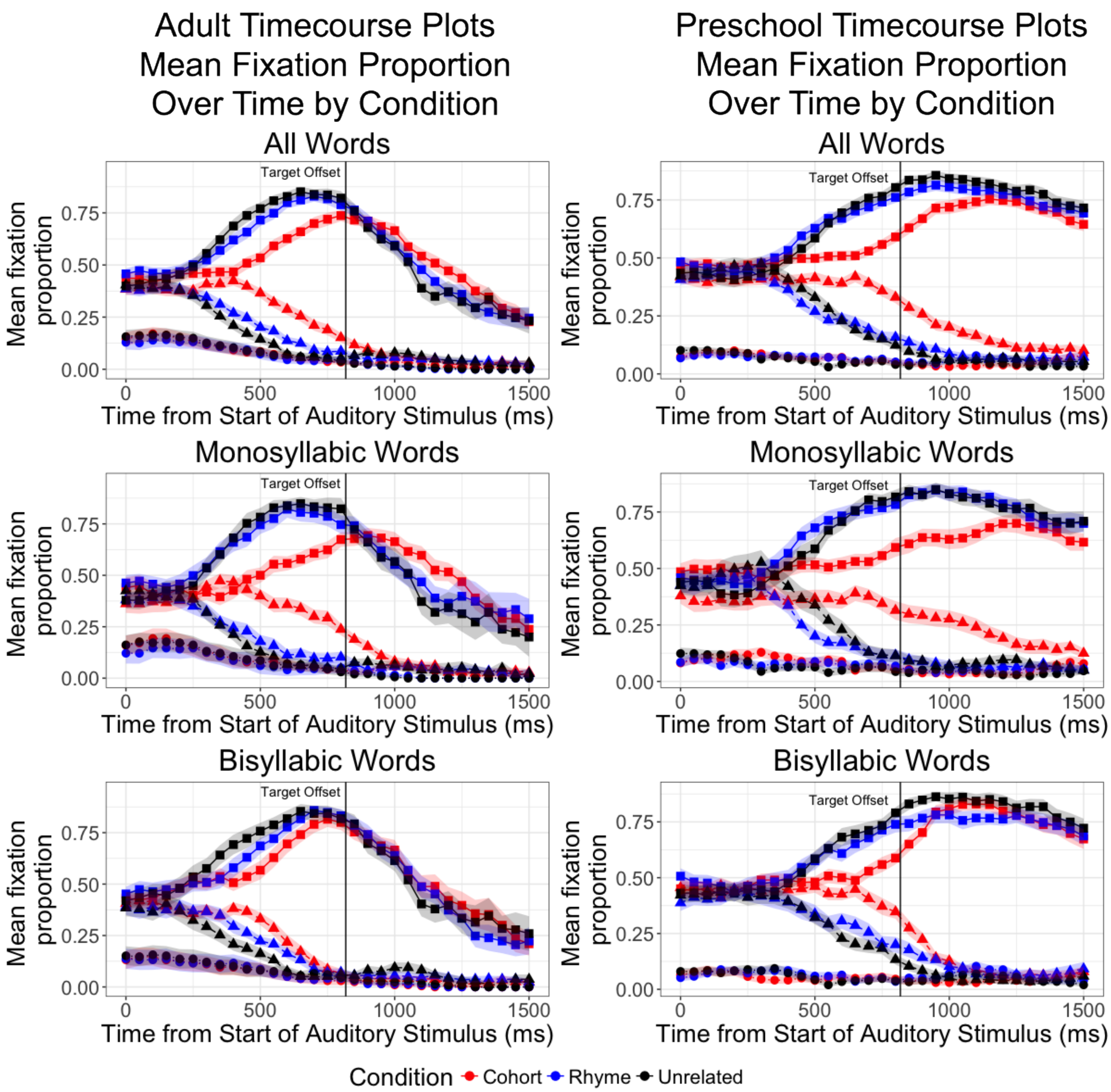
Object Label Knowledge

Results from the object labeling post-test revealed that the preschool participants had familiarity with most of the 108 images presented. On average, children could provide labels for 89 (*SD* = 6, range {77,97}) of the 108 items. Although they were only able to produce an exact label for approximately 80% of the objects in the experiment, the preschool participants still had knowledge of almost all of the objects as evidenced by their high trial accuracy score (e.g., mean accuracy of 49 out of 54 trials).

Eye tracking

Descriptive overview. Visual examination of the timecourse plots (Figure 2) revealed differences between participant groups, as well as between types of phonological competitors, and potential interactions of phonological competitor type with mono- vs. bisyllabic words. Collapsed across syllables, the adult group (left panels) demonstrated strong cohort effects with a trend toward rhyme effects. However, potential differences emerged for mono- vs. bisyllabic items. Specifically, for monosyllabic words, cohort effects were strong and rhyme effects were weak. For bisyllabic words, cohort effects appeared faster than in the monosyllabic words and rhyme effects appeared robust.

A somewhat different pattern of effects emerged for the preschool group (right panels of Figure 2). Across syllables, the preschool group showed strong cohort competition, with a possible trend towards stronger cohort competition for monosyllabic than bisyllabic words, as observed with the adult group. However, the preschool group had an atypical competition pattern for rhymes. Early in the timecourse for all words, a pattern of competition emerged where Unrelated trials competed more strongly than Rhyme trials. This pattern is also evident in monosyllabic words but absent in bisyllabic words. We attempted to identify potential



contributions of this unexpected pattern including comparing words pairs for animacy (e.g., was one item animate and the other item inanimate), frequency (e.g., was one word more common than the other word) and production (e.g., whether or not the child was able to produce the label

Figure 2. Timecourse plots of eye movements by object and condition for each participant group. Error bands indicate one standard error

for one word but not the other). However, even after for control for these potential confounds, the data pattern remained stable leading us to believe this is likely due to noise in the data from our small sample size. For bisyllabic items, the pattern is more similar to that of the adult group, with a possible presence of a rhyme effect.

Growth Curve Analysis: Adult group, Model 1 (Main Effects of Phonological Condition). The following analyses were conducted using an analysis window from 0 ms to 1000 ms after word onset (see justification above). All orthogonal polynomial terms, including the linear (i.e., slope) term, quadratic, and cubic, significantly contributed to modeling the Unrelated target baseline. There was an effect of the Cohort trials compared to the Unrelated trials as evidenced by significantly lower intercept (lower mean fixation proportion) and significantly more positive quadratic (less bowing as seen in Figure 2) and cubic components[2]. There was also an effect of Rhyme on the quadratic component compared to Unrelated trials, similar to that of the cohort trials, with rhyme trials having a significantly more positive quadratic component, suggesting less bowing of the curve and greater competition.

Growth Curve Analysis: Adult group, Model 2 (Main Effects of Syllable Condition). Again, all orthogonal polynomial terms significantly contributed to model fit (Table 5). There was a significant effect of syllable with a higher mean fixations proportion to bisyllabic words compared to monosyllabic words as seen by the higher intercept of bisyllabic words over monosyllabic words. See Tables 4 and 5 for the fixed effect parameter estimates, standard errors and *p*-values estimated using the normal approximation for the *t*-values for the GCA for the adult

[2] Visual inspection suggests a shallower slope for the Cohort condition compared to the Unrelated, but the slope (linear) term is not significant in this case. Note that the growth curve analysis is using maximum likelihood estimation to find the best fit to the observed data by weighted combinations of intercept, slope, quadratic, and cubic terms. In this case, better fit is obtained by using the quadratic and cubic terms to "unbow" the curve without altering the slope estimate.

participants for Models 1 and 2. Consistent with this finding, models like TRACE (McClelland & Elman, 1986) predict greater overall activation for longer words, due to greater total bottom-up input. Pitt and Samuel (2006) report enhanced lexical effects for longer words consistent with this prediction.

Table 4

Parameter Estimates for Analysis of Effect of Phonological Condition on Fixations for Adult Group.

	Estimate	Std. Error	*t* value	*p*	Sig
Intercept	0.649	0.024	26.645	<.001	*
Linear (slope)	0.514	0.026	19.580	<.001	*
Quadratic	-0.436	0.026	-16.558	<.001	*
Cubic	-0.252	0.026	-9.591	<.001	*
Cohort (Intercept)	-0.082	0.008	-10.283	<.001	*
Cohort (Slope)	-0.021	0.037	-0.559	0.576	n.s.
Cohort (Quadratic)	0.438	0.037	11.845	<.001	*
Cohort (Cubic)	0.083	0.037	2.255	0.024	*
Rhyme (Intercept)	-0.010	0.008	-1.213	0.225	n.s.
Rhyme (Slope)	-0.046	0.037	-1.254	0.210	n.s.
Rhyme (Quadratic)	0.157	0.037	4.247	<.001	*
Rhyme (Cubic)	-0.027	0.037	-0.729	0.466	n.s.

Table 5

Parameter Estimates for Analysis of Effect of Syllable Condition on Fixations for Adult Group.

	Estimate	Std. Error	*t* value	*p*	Sig
Intercept	0.600	0.024	24.847	<.001	*
Linear (slope)	0.464	0.022	20.878	<.001	*
Quadratic	-0.244	0.022	-10.967	<.001	*

Cubic	-0.224	0.022	-10.086	<.001	*
Bisyllabic (Intercept)	0.036	0.007	5.252	<.001	*
Bisyllabic (Slope)	0.059	0.031	1.875	0.061	n.s.
Bisyllabic (Quadratic)	0.014	0.031	0.442	0.659	n.s.
Bisyllabic (Cubic)	-0.017	0.031	-0.532	0.595	n.s.

Growth Curve Analysis: Adult group, Model 3 (Full model with Phonological Condition and Syllable Condition). All orthogonal polynomial terms included in the model (e.g., linear, quadratic, cubic), significantly contributed to modeling the Unrelated, Monosyllabic target baseline. We now turn to how the timecourse for targets differed from this baseline in other conditions.

There was a clear phonological competition effect of the monosyllabic Cohort trials compared to the Unrelated monosyllabic trials as evidenced by significantly lower intercept (lower mean fixation proportion) and a significantly more positive quadratic (less bowing as seen in Figure 2) and cubic components.

We also observe a similar pattern of competition between the monosyllabic Rhyme and monosyllabic Unrelated conditions. The monosyllabic Rhyme trials had a significantly lower slope (slower to get to target) and significantly more positive quadratic component (less bowing as seen in Figure 2).

Examining the effect of Syllable, there was a significant effect of syllable length on the Bisyllabic Unrelated trials compared to Monosyllabic Unrelated trials as indicated by a significantly higher intercept (higher mean fixation proportion) and significantly more positive quadratic component (again less bowing; see Figure 2).

Evaluation of the relationship between Syllable and Condition revealed a significant interaction between Cohort Condition and Bisyllabic trials. The significant intercept interaction

of Cohort and syllable is consistent with the smaller cohort effect observed for bisyllables in Figure 2 (formally, the intercept for Bisyllabic Cohort trials was significantly lower than predicted from the effects of Cohort and Syllable alone). The significant quadratic interaction indicates more upward bowing of the Cohort at Bisyllabic target curve than would be predicted from the addition of quadratic terms for Cohort and Bisyllabic effects, again reflecting a weaker Cohort effect for bisyllabic than monosyllabic targets.

Table 6 outlines the fixed effect parameter estimates, standard errors and *p*-values estimated using the normal approximation for the *t*-values for the GCA for the adult participants.

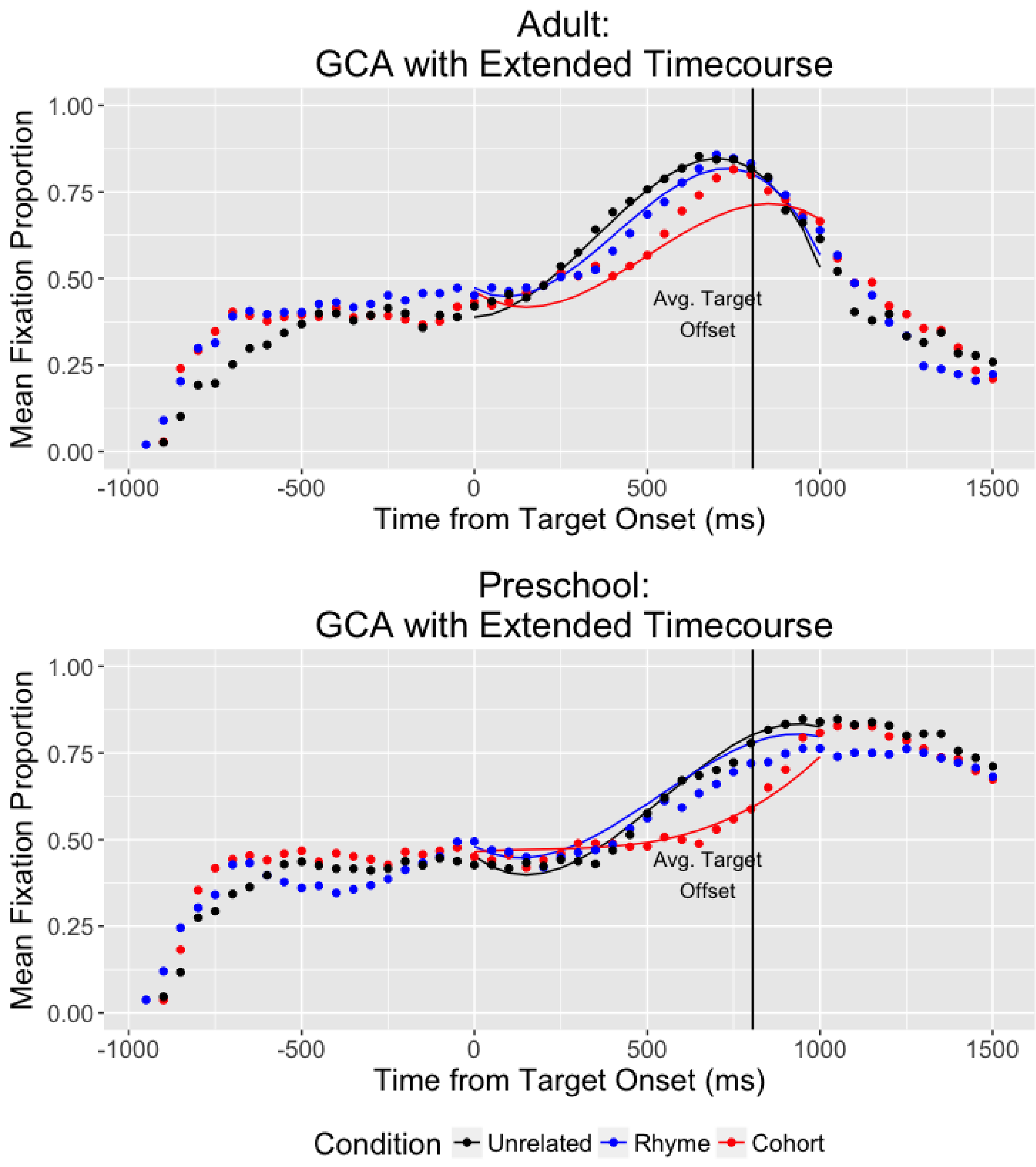


Figure 3. These figures show the model fit data (solid lines) using the 1000 ms analysis window starting at time 0 and the actual data (circles) for an extended timecourse from the presentation of the visual stimulus through 1500 ms after the onset of the target word.

Table 6

Parameter Estimates for Analysis of Effect of Phonological Condition and Syllable Condition on Fixations for Adult Group.

	Adult Participants (*n* = 22)				
	Estimate	Std. Error	*t*	*p*	Sig.
Intercept	0.636	0.025	25.468	<.001	*
Linear (slope)	0.524	0.037	14.322	<.001	*
Quadratic	-0.488	0.037	-13.304	<.001	*
Cubic	-0.279	0.037	-7.616	<.001	*
Cohort (intercept)	-0.108	0.011	-9.707	<.001	*
Cohort (slope)	-0.068	0.051	-1.314	0.189	n.s.
Cohort (quadratic)	0.590	0.051	11.469	<.001	*
Cohort (cubic)	0.145	0.051	2.826	0.005	*
Rhyme (intercept)	0.001	0.011	0.057	0.954	n.s.
Rhyme (slope)	-0.117	0.051	-2.276	0.023	*
Rhyme (quadratic)	0.138	0.051	2.678	0.007	*
Rhyme (cubic)	0.014	0.051	0.281	0.779	n.s.
Bisyllabic (intercept)	0.026	0.011	2.288	0.022	*
Bisyllabic (slope)	-0.019	0.052	-0.371	0.710	n.s.
Bisyllabic (quadratic)	0.103	0.052	1.984	0.047	*
Bisyllabic (cubic)	0.053	0.052	1.019	0.308	n.s.
Cohort x Bisyllabic (intercept)	0.052	0.016	3.279	0.001	*
Cohort x Bisyllabic (slope)	0.094	0.073	1.295	0.195	n.s.
Cohort x Bisyllabic (quadratic)	-0.304	0.073	-4.178	<.001	*
Cohort x Bisyllabic (cubic)	-0.124	0.073	-1.704	0.088	n.s.
Rhyme x Bisyllabic (intercept)	-0.021	0.016	-1.312	0.190	n.s.
Rhyme x Bisyllabic (slope)	0.142	0.073	1.950	0.051	n.s.
Rhyme x Bisyllabic (quadratic)	0.039	0.073	0.533	0.594	n.s.
Rhyme x Bisyllabic (cubic)	-0.083	0.073	-1.138	0.255	n.s.

Growth Curve Analysis: Preschool group, Model 1 (Main Effects of Phonological Condition). Again**,** the following analyses were conducted using a 1000 ms analysis window from 0 ms to 1000 ms after word onset. Similar to the adult model, all orthogonal polynomial terms, the linear, quadratic, and cubic, significantly contributed to modeling the Unrelated target baseline. There was an effect of the Cohort trials compared to the Unrelated trials as evidenced by significantly lower intercept (lower mean fixation proportion) and a significantly more positive quadratic (less bowing as seen in the top right panel of Figure 2) and cubic components. There was also an effect of Rhyme trials on the slope compared to Unrelated trials with rhyme items having a lower slope compared to unrelated items. This suggests it takes the participants longer to get to Rhyme targets compared to Unrelated targets.

Growth Curve Analysis: Preschool group, Model 2 (Main Effects of Syllable Condition). All orthogonal polynomial terms, quadratic, and cubic, significantly contributed to model fit. There was a significant effect of syllable with a lower mean fixation proportion to bisyllabic words compared to monosyllabic words as seen by the lower intercept of bisyllabic words over monosyllabic words. This pattern is opposite to what we observed in the adult group. This positive quadratic effect may reflect a later disambiguation point and slower arrival to the target image. It is possible that our analysis window of 1000 ms removed potentially equivalent or greater fixations in the bisyllabic condition[3]. Tables 7 and 8 show the fixed effect parameter estimates, standard errors and *p*-values estimated using the normal approximation for the *t*-values

[3] That is, there is a tension between using GCA windows for the adults and children that have identical absolute parameters (0,1000 ms) vs. similar *relative* windows (e.g., continuing the GCA window for children to 1500 ms would make the overall curve "shape" more similar to the 0-1000 ms GCA window for adults. Due to time constraints, I have not yet explored the potential ramifications of using different windows for the two groups.

for the GCA for the preschool participants for Models 1 and 2.

Table 7

Parameter Estimates for Analysis of Effect of Phonological Condition on Fixations for Preschool Group.

	Estimate	Std. Error	*t* value	*p*	Sig
Intercept	0.603	0.011	54.111	<.001	*
Linear (slope)	0.731	0.025	28.771	<.001	*
Quadratic	0.085	0.025	3.359	0.001	*
Cubic	-0.177	0.025	-6.965	<.001	*
Cohort (Intercept)	-0.07	0.008	-8.936	<.001	*
Cohort (Slope)	-0.406	0.036	-11.284	<.001	*
Cohort (Quadratic)	0.079	0.036	2.21	0.027	*
Cohort (Cubic)	0.224	0.036	6.221	<.001	*
Rhyme (Intercept)	0.014	0.008	1.748	0.08	n.s.
Rhyme (Slope)	-0.126	0.036	-3.497	<.001	*
Rhyme (Quadratic)	-0.033	0.036	-0.921	0.357	n.s.
Rhyme (Cubic)	0.04	0.036	1.1	0.271	n.s.

Table 8

Parameter Estimates for Analysis of Effect of Syllable Condition on Fixations for Preschool Group.

	Estimate	Std. Error	*t* value	*p*	Sig
Intercept	0.593	0.011	55.316	<.001	*
Linear (slope)	0.553	0.022	25.41	<.001	*
Quadratic	0.046	0.022	2.119	0.034	*
Cubic	-0.13	0.022	-5.96	<.001	*
Bisyllabic (Intercept)	-0.018	0.007	-2.642	0.008	*
Bisyllabic (Slope)	0.002	0.031	0.056	0.955	n.s.
Bisyllabic (Quadratic)	0.109	0.031	3.551	<.001	*
Bisyllabic (Cubic)	0.081	0.031	2.628	0.009	*

Growth Curve Analysis: Preschool group, Model 3 (Full model with Phonological Condition and Syllable Condition). All orthogonal polynomial terms contributed significantly to modeling the Unrelated, Monosyllabic target baseline (see Table 9). We now turn to how the timecourse for targets differed from this baseline in other conditions.

Similar to the pattern observed in our adult group, there was a strong phonological competition effect of the monosyllabic Cohort trials compared to the Unrelated monosyllabic trials as evidenced by significantly lower intercept (lower mean fixation proportion) and a significantly more positive quadratic (less bowing as seen in Figure 2, right panel) and cubic components.

An unusual pattern of competition effects emerged between the monosyllabic Rhyme and monosyllabic Unrelated conditions. The monosyllabic Rhyme trials had a significantly *higher* intercept (higher mean fixation proportions) compared to the monosyllabic Unrelated trials. This effect can be clearly observed in Figure 2, right panel. Potential explications and implications of this unexpected finding are examined in the discussion.

The effect of Syllable was less clear in this participant group compared to our adult group. There was a significant effect of syllable length, with significantly more positive quadratic and cubic terms required to model the change from monosyllabic to bisyllabic, reflecting the "flatter" trajectories for bisyllabic targets. Evaluation of the relationship between Syllable and Condition revealed a significant interaction between Cohort Condition and Bisyllabic trials with Cohort Bisyllabic trials having a higher slope (slower to get to target) suggesting reduced Cohort effect at the Bisyllabic level compared to the Monosyllabic level.

Table 9 outlines the fixed effect parameter estimates, standard errors and *p*-values estimated using the normal approximation for the *t*-values for the GCA for the adult participants

Table 9.

Parameter Estimates for Analysis of Effect of Phonological Condition and Syllable Condition on Fixations for Preschool Group.

	Preschool Participants (*n* = 23)				
	Estimate	Std. Error	*t*	*p*	Sig.
Intercept	0.609	0.012	49.169	<.001	*
Linear (slope)	0.749	0.036	21.093	<.001	*
Quadratic	0.045	0.036	1.271	0.204	n.s.
Cubic	-0.226	0.036	-6.373	<.001	*
Cohort (intercept)	-0.079	0.011	-7.175	<.001	*
Cohort (slope)	-0.528	0.050	-10.509	<.001	*
Cohort (quadratic)	0.061	0.050	1.209	0.227	n.s.
Cohort (cubic)	0.215	0.050	4.280	<.001	*
Rhyme (intercept)	0.029	0.011	2.629	0.009	*
Rhyme (slope)	-0.059	0.050	-1.183	0.237	n.s.
Rhyme (quadratic)	-0.058	0.050	-1.149	0.251	n.s.
Rhyme (cubic)	0.075	0.050	1.487	0.137	n.s.
Bisyllabic (intercept)	-0.013	0.011	-1.221	0.222	n.s.
Bisyllabic (slope)	-0.035	0.050	-0.707	0.480	n.s.
Bisyllabic (quadratic)	0.080	0.050	1.602	0.109	n.s.
Bisyllabic (cubic)	0.099	0.050	1.962	0.050	*
Cohort x Bisyllabic (intercept)	0.017	0.016	1.103	0.270	n.s.
Cohort x Bisyllabic slope)	0.244	0.071	3.439	0.001	*
Cohort x Bisyllabic (quadratic)	0.038	0.071	0.528	0.598	n.s.
Cohort x Bisyllabic (cubic)	0.017	0.071	0.244	0.807	n.s.
Rhyme x Bisyllabic (intercept)	-0.030	0.016	-1.948	0.051	n.s.
Rhyme x Bisyllabic (slope)	-0.133	0.071	-1.867	0.062	n.s.
Rhyme x Bisyllabic (quadratic)	0.049	0.071	0.692	0.489	n.s.
Rhyme x Bisyllabic (cubic)	-0.070	0.071	-0.989	0.323	n.s.

Discussion

The purpose of this study was to evaluate the pattern of phonological competition effects, with particular focus on rhyme competition, in a group of pre-reading children compared to that of fluent adults readers using a downward extension of the visual world paradigm adapted for very young children. The aim was to compare distinctive predictions from two groups of developmental theories. Wholistic-emergent views (Walley, 2003; Fowler, 1991) hold that young children have less phonetically and temporally precise representations of spoken words than adults, leading to a prediction of stronger rhyme effects (or rhyme effects more similar to cohort effects) in young children. Accessibility views (Morais, Bertelson, Carey & Alegria, 1986) hold that rhyme competition should emerge around the onset of reading acquisition, either because reading reorganizes phonological representations (Ainsworth, Welbourne, & Hesketh, 2016) or due to a coincidental developmental progress (Liberman, Shankweiler, & Liberman, 1989); such views predict an absence of rhyme effects in pre-readers. In fact, our results are not wholly consistent with either view, and provide new constraints on developmental theories of spoken word recognition. In the remainder of this discussion, we review the differences in phonological competition between our adult and child groups and the stark variation in competition effects observed between shorter and longer words. Our findings suggest that even pre-readers show Cohort effects similar to that of adults and weaker rhyme effects -- but rhyme effects nonetheless. Moreover, our child group appears less sensitive to Rhymes in monosyllabic words compared to bisyllabic words.

Phonological Competition in Preschool Children versus Adults

Unsurprisingly, developmental differences emerged within the pattern of phonological

competition between our child and adult groups. Overall, our preschool participants took longer to move their eyes to the target compared to that of our adult participants, although both groups eventually reached similar proportions of target fixations. These timing differences are similar to those observed by Rigler and colleagues (2015) who demonstrated differences in the timing of phonological competition between 9 year olds and 16 year olds in a spoken word recognition task. The slower timecourse observed in the child group compared to the adult group likely reflects changes to processing efficiency observed over the course of development (Riger et al., 2015).

Despite differences in timing, the overall eye movement patterns, when collapsed across syllables, reveal that preschoolers are more similar than dissimilar in their processing of spoken words when compared to adults. Both groups showed strong Cohort effects, replicating previous findings on the relative importance of word onsets (Magnuson et al., 2003; Allopenna et al., 1998). Weaker rhyme effects were observed in both groups, consistent with previous findings (Allopenna et al., 1998) and with predictions of the TRACE model (McClelland & Elman, 1986), as discussed in the introduction.

Syllable Structure Effects on Competition by Group

When lexical activation is compared for mono- versus bisyllabic words, we see stark differences between our groups. For our adult participants, we observe weak rhyme effects and relatively slow emergence of cohort competition for monosyllabic trials. For bisyllabic trials, robust rhyme effects are present, along with faster emergence of cohort effects. Phonetic similarity or overlap may explain the differences we see in competition patterns for shorter versus longer words, especially in our adult participants. In monosyllabic cohort trials, there is a greater proportion of

overlapping phonetic information compared to bisyllabic cohort trials, thus less disambiguating information is available to the listener. Additionally, the monosyllabic Cohort words are slightly longer in duration than that of the two syllable Cohort words thus the disambiguating information may come later in the signal. These factors may explain the differences in competition between mono and bisyllabic Cohort trials in our adult participants. In terms of the rhyme trials, the degree of phonetic overlap is reversed: words in the bisyllabic rhyme condition have more overlapping phonemic information than monosyllabic rhymes, which may explain the increased competition in the bisyllabic rhyme trials.

Collapsed across syllables, the pattern of phonological competition in our preschool group appears similar to that of our adult participants. However, the preschool participants also demonstrated distinct patterns of activation for monosyllabic versus bisyllabic trials. Monosyllabic cohort effects were similar to those of the adult group, with slow emerging but strong Cohort effects; however, rhyme competition was absent. Surprisingly, the phonologically Unrelated trials showed greater competition than the Rhyme condition trials. Approximately 35% of items contributed to this reversal. With these items removed, the reversal disappears, but there is still no evidence for a rhyme effect for monosyllable targets in pre-readers. Based on a suggestion from a colleague (Yee, personal communication), we tested whether many of these problematic items might have an imbalance in animacy. On this hypothesis, if there is a pair where one item is animate and one is inanimate, the animate item should attract greater fixation proportions prior to target word onset. Note that for this explanation to be sound, we would have to find that the animate item would attract greater fixation proportions prior to target onset both when it served as target and when it served as distractor. This was not the case for most of these pairs. Such asymmetry suggests that this unexpected reversal may be noise due to our small

sample size per cell of the experimental design. More participants will be enrolled, so that we may confirm or falsify this possibility.

The TRACE model may help us better understand the absence of rhyme effects in the monosyllabic trials in our preschool group. TRACE stresses the importance of top-down feedback from the lexical layer to the phonemic layer, and it is possible that top-down feedback plays a critical role in rhyme activation in TRACE. Studies of children suggest the top-down control that modulates phonological information increases with age and that children's top-down processing of phonological information is less strong compared to adults (Bitan, Cheon, Lu, Burman & Booth, 2009). Since children have less experience with words in general, attenuated top-down modulation of word activation seems plausible (Malins et al., 2014). It is possible that the atypical pattern of rhyme competition, or lack thereof, in our monosyllabic rhyme condition for our preschool group is a result of limited top-down activation of lexical information coupled with the limited proportion of phonemic overlap between the target and competitor words in the monosyllabic rhyme trials. Simulations could be useful in helping us determine if this explanation is plausible.

Theoretical Implications

Results from this study suggest that preschool children process words in a sequential fashion – as adults do. These findings are comparable to infant and toddler studies that demonstrate incremental processing of the speech signal using mispronunciation or mismatch paradigms (Swingley, 2009; Swingley & Aslin, 2000; White & Morgan, 2008). Our findings, coupled with findings from recent infant and toddler work, fail to support the hypothesis that young children's lexical representations are wholistic, and/or that they do not attend to fine-

grained phonetic detail or temporal information. Our study results also fail to support the accessibility view of word perception. Although we see incremental processing of words in our preschool group, the accessibility view posits that rhyme competition should only emerge once metacognition of sounds appears and after the start of direct reading instruction. The presence of rhyme competition in our pre-reading group suggests that children are sensitive to rhyme prior to learning to read.

Our findings support an *information processing* view in that young children do in fact represent temporal information and phonological detail. Even very small lexicons require fine grain detail and temporal order in order for word recognition to take place. This is supported by data that suggest around age three, words in their lexicon are confusable with approximately six other words based on phonological similarity (Coady & Aslin, 2003). This suggests that children, well before learning to read, have considerable sensitivity to the speech signal.

Study Limitations and Future Directions

Despite promising findings, this study has several limitations that should be addressed. While the total sample sizes for adults and children are larger than those of many comparable visual world studies, counter-balancing constraints resulted in small samples in each list (~5 per list). Because of counterbalancing, this means we have only ~5 participants in each group who experience a specific item in a specific role (e.g., as the target or distractor within a particular phonological condition). As discussed above, the small sample size per list may have contributed to the unusual pattern of competition in the monosyllabic Rhyme and Unrelated trials for the preschool group.

While the presence of very subtle rhyme effects in pre-reading preschool children in this

sample is encouraging, generalizability of these findings is limited. Children in this sample were all recruited from middle to upper middle class families who are attending a preschool program. Phonological awareness, although maybe not explicitly, is typically part of the preschool curriculum. Thus, these children, although not readers, may have had exposure to phonological awareness instruction.

Subsequent iterations of this study will increase sample size, downward extend the task to younger children not exposed to phonological awareness instruction, and also include school-age, fluent readers (allowing us to being to map when adult-like phonological competition emerges). Moreover, we will collect individual differences measures on reading, language and cognition to better understand the dynamics between spoken word recognition, reading and cognition throughout the course of development.

Appendix 1

Word 1	Word 2	Condition	Syllables
bat	bath	Cohort	1
bed	belt	Cohort	1
bus	bug	Cohort	1
cloud	clown	Cohort	1
coat	comb	Cohort	1
couch	cows	Cohort	1
moon	moose	Cohort	1
mouse	mouth	Cohort	1
toes	toast	Cohort	1
bubbles	butter	Cohort	2
bunny	button	Cohort	2
candy	camera	Cohort	2
chicken	children	Cohort	2
kitty	kitchen	Cohort	2
penguin	penny	Cohort	2
pillow	pickle	Cohort	2
pizza	people	Cohort	2
popcorn	potty	Cohort	2
cake	rake	Rhyme	1
cat	hat	Rhyme	1
dish	fish	Rhyme	1
keys	bees	Rhyme	1
pen	men	Rhyme	1
sand	hand	Rhyme	1
shoe	glue	Rhyme	1
star	car	Rhyme	1
toy	boy	Rhyme	1
flower	shower	Rhyme	2
jelly	belly	Rhyme	2
mitten	kitten	Rhyme	2
money	honey	Rhyme	2
noodles	poodles	Rhyme	2

parrot	carrot	Rhyme	2
rocket	pocket	Rhyme	2
sandal	candle	Rhyme	2
sweater	letter	Rhyme	2
bear	pants	Unrelated	1
bird	sock	Unrelated	1
book	nose	Unrelated	1
cheese	teeth	Unrelated	1
corn	soap	Unrelated	1
dog	milk	Unrelated	1
doll	juice	Unrelated	1
feet	horse	Unrelated	1
frog	cup	Unrelated	1
basket	police	Unrelated	2
bottle	zipper	Unrelated	2
doctor	muffin	Unrelated	2
donut	finger	Unrelated	2
hammer	pumpkin	Unrelated	2
monkey	soda	Unrelated	2
present	tractor	Unrelated	2
pretzel	sneaker	Unrelated	2
shovel	cookie	Unrelated	2

Note. Word 1 and Word 2 each served as a target and a distractor.

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