Phonological Working Memory and Phonological Awareness

Development of an Experimental Pseudoword Repetition Task

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Dedication

This work grew from a project I began working on at Haskins Laboratories in Fall 2007. I am deeply indebted to those at Haskins who have made all this possible. I'd like to thank Dave Braze, my tirelessly supportive advisor, for always showing me how to answer my questions, rather than just answering them himself. I'd also like to thank Professor Stephen Anderson for our class trips to Anna Liffey's. To my friends and housemates – thank you for making this year so much more fun. To my family – I love you.

Nate

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Much research indicates that reading achievement is strongly associated with phonologically-grounded capacities, and that weaknesses in such capacities are linked to reading disability (e.g., Lonigan, Schatschneider, & Westberg, 2008; Scarborough, 2005; see also Bus & Van Ijzendoom, 1999; De Jong & Van Der Leij, 1999; Hansen & Bowey, 1994; Mann & Liberman, 1984; Ramus, et al., 2003; Staal & Murray, 1994; White, et al., 2006) The primary goal of this study, then, is to develop and validate pseudoword repetition task with which to assess phonological working memory – one of several phonologically-grounded capacities implicated in reading achievement – in young, pre-reading children, and apply this task to an investigation of the relationship between phonological awareness and phonological working memory. This task is developed in the context of a proposed longitudinal study whose goal is to evaluate the relative contributions of various cognitive and linguistic capacities to reading acquisition. Additionally, the task developed in this project may serve as part of a model for an early diagnostic assessment for a weakness in phonological skills that may signal future reading difficulties. Following the development of this task, we deploy it in combination with a well-documented, standardized assessment of phonological awareness, the phonological awareness section of the Test of Preschool Early Literacy (Lonigan, Wagner, & Torgesen, 2007), to probe the relationship between phonological working memory and phonological awareness in three- and four-year-olds. We also adapt the phonological working memory task for use in a battery of psychometric tasks administered to 16- to 24-year-olds with a wide range of literacy skills, to assess the relationships between performance on the experimental task and standard measures of verbal and visual memory and phonological awareness. With these two cohorts, we will also be able to compare the relationships between phonological working memory and phonological awareness at two different developmental stages. The remainder of this introductory section motivates the need for an instrument which can assess phonological working memory in young, pre-literate children, and introduces issues and challenges that arise in the context of preschool assessment.

Reading and phonologically-grounded capacities

According to Gough and Tunmer's (1986) Simple View of Reading, reading comprehension is the product of two (complex) capacities: decoding skill and oral language comprehension (RC = D x LC). Oral language comprehension is self-evidently the ability to discern meaning from spoken language. It comprises the phonetic, phonological, morphological, syntactic, semantic, and pragmatic skills necessary to speak and understand a language. Decoding skill is the ability to translate print information into a linguistic form. As several authors have noted, these two components vary in their importance to reading comprehension at different ages. A survey of reading research by Gough, Hoover, and Peterson (1996) found that the correlation between word recognition skill (decoding) and reading comprehension dropped from .61 to .39 between primary grades and college, while the correlation between listening comprehension and reading comprehension rose from .41 to .60 in the same time span. Most beginning readers have lexical and semantic knowledge that outstrips their decoding ability; for them, decoding skill, and not oral language comprehension, is the limiting factor on reading comprehension. In fact, in a longitudinal study, Catts, Hogan, and Adlof (2005) found that, in second grade, decoding skill uniquely accounted for 27% of variance in reading comprehension, with oral language comprehension uniquely accounting for 9% of reading comprehension variance, and 40% of variance being shared; by eighth grade, on the other hand, decoding skill uniquely accounted for only 2% of variance, with oral language comprehension uniquely accounting for 36% of reading comprehension variance, and 36% of variance being shared. Given the primacy of decoding skill for beginning readers (and its continued relevance for more experienced readers), understanding the cognitive prerequisites of decoding skill is a crucial part of understanding reading acquisition.

Decoding skill requires both phoneme awareness and phonological working memory. Decoding skill is predicated on letter knowledge and the alphabetic principle: Beginning readers must identify letters, grasp grapheme-phoneme correspondences (i.e., the alphabetic principle: that, in alphabetic orthographies, letters generally represent phonemes), and then use their knowledge of those correspondences and awareness of phonemes to sound out the words. As they sound out the words, beginning readers must store the words' phonological representations in phonological working memory to access their meanings (tagged with the phonological form) from the lexicon. Phonological working memory is linked to reading achievement not only through decoding skill, but also through oral language comprehension. Vocabulary acquisition depends on phonological working memory capacity (Avons, Wragg, Cupples, & Ludgrove, 1998; Gathercole & Baddely 1993; Gathercole, Service, Hitch, Adams, & Martin, 1999). Empirical results clearly link both phonological working memory and phonological awareness to reading achievement. In a survey of longitudinal reading research, Scarborough (1998, 2005) found the average correlation between memory for phonological material, as assessed in kindergarten, and later reading achievement to be .33, and the average correlation between phonological awareness, as assessed in kindergarten, and later reading achievement to be .46. In another survey, Lonigan, Schatschneider, and Westberg (2008) found the correlation between phonological working memory, as assessed in preschool, and later reading comprehension to be .51, and that for the relationship between phonological awareness as assessed in preschool and later reading comprehension to be .36.

Many researchers have confirmed the importance of both phonological working memory and phoneme awareness to later reading achievement. Mann and Liberman (1984) found that both phonological awareness and phonological memory as assessed in kindergarten predicted reading success in first grade. Hansen and Bowey (1994) found that both phonological awareness and verbal working memory each relate uniquely to reading ability in second graders. Additionally, a longitudinal study of Dutch students showed that phonological memory, rapid serial naming, and phonological awareness each had unique influences on reading achievement from kindergarten through second grade (De Jong & Van Der Leij, 1999). It is clear that both phonological awareness and phonological working memory have independent relationships with reading.

Scarborough (2005) notes that future reading achievement is predicted as well, and in many cases better, by measures taken at three and four years old as by the same measures taken at five years old. This indicates that an assessment of phonological working memory targeted for three- and four-year-olds will be a valuable contribution to the study of the development of reading-related cognitive skills.

Pseudoword repetition tasks and assessing preschoolers

One well-established method of testing phonological memory in grade-school children is a a pseudoword repetition task (Gathercole, Willis, Baddeley, & Emslie, 1994). In this type of task, children are asked to repeat increasingly long nonce words, until they can no longer repeat the pseudowords. In this project, we adapt such a task for use with a preschool-aged population. Additionally, we adapt our task for use in a large battery of tasks targeting various literacy-related skills, administered to young adults.

In fact, pseudoword repetition tasks have been occasionally used with age groups which overlap with our target population, although there are significant challenges in assessing phonological working memory in this young a population because task refusal is a recurrent problem. Gathercole and Adams (1993) used pseudoword repetition in an investigation of phonological working memory in 2- and 3-year olds; however, their study experienced an attrition rate of over 50% of participants – more participants failed to complete the study than completed it. In that study, real-word and pseudoword repetition were each correlated with both articulation rate and vocabulary knowledge. Hoff, Core, and Bridges (2008) used a pseudoword repetition task as a measure of phonological working memory in 20- to 24-month-old children, and found that performance on the pseudoword repetition task was highly correlated with both vocabulary knowledge and real-word repetition skills. Pseudoword repetition was a more demanding task than real-word repetition.

Gathercole (1995) used a pseudoword repetition task to longitudinally test verbal working memory in four- and five-year-olds. The stimuli for this study differentiated between high-wordlikeness and low-wordlikeness pseudowords. Results indicated that vocabulary knowledge was more closely related to recall of high-wordlikeness pseudowords than low-wordlikeness pseudowords at age five, that digit span (another common measure of verbal working memory, in which participants are asked to recall strings of randomized digits) was more closely related to recall of low-wordlikeness pseudowords than high-wordlikeness pseudowords at both ages. These findings support the idea that vocabulary knowledge plays into children's pseudoword repetition skills, as more wordlike pseudowords are easier for children with larger vocabularies. Additionally, decoding skill (word recognition) at age five was more closely related to recall of low-wordlikeness pseuodowords than high-wordlikeness pseudowords at both ages. This finding suggests that, because of the mediating effect of vocabulary knowledge on recall of high-wordlikeness pseudowords, recall of low-wordlikeness pseudowords is more dependent on verbal working memory. Because recall of low-wordlikeness pseudowords is more closely linked to word recognition, these findings also suggest that verbal working memory at ages four and five is strongly implicated in reading success at age five.

With the challenge of noncompliant participants so common in our target population, a major component of the current project was to develop a pseudoword repetition task that would maximize the cooperation and participation of preschool children. Only with such a task can the relationship between phonological working memory and phonological awareness be probed.

Interference for rhyming items in pseudoword repetition tasks

An interesting interaction between decoding skill and phonological working memory was first documented in Mark, Shankweiler, Liberman, and Fowler (1977). In a study of second-graders, they found that participants who had higher levels of decoding skill were less successful at recalling written lists of rhyming words with diverse spellings than written lists of non-rhyming words. Their lower-decoding-skill counterparts were less successful at pseudoword recall overall, but did not display a disparity in recalling rhyming versus non-rhyming material. This finding supports the idea of cognitive interference based on the phonological similarity of the rhyming items: participants with better decoding skill would likely be more sensitive to phonologically-similar (i.e. rhyming) items. The participants with lower levels of decoding skills may have been recognizing the words by sight (i.e., using visuospatial working memory), rather than decoding each word, which would explain their reduced interference for the rhyming items.

The phonological interference effect for print stimuli, measured in Mark, et al. (1977) was redocumented by Olson, Davidson, Kliegl, and Davies (1984). The stimuli in this procedure were presented visually and the participants indicated whether or not they had already seen the pseudoword. Results showed that reading-disabled children, age 7.8-16.8 years, displayed the same phonological interference as their developmentally normal peers, but at an older age. This result is consistent with a developmental delay in phonological processing among reading-disabled children. Another trend was that normally progressing readers' interference effect decreased with age and reading experience, which the authors speculate demonstrates that as readers become more experienced, they depend less on phonological representations of words for printed word recognition. The number of errors in recognition increased when subjects read the pseudowords aloud before responding, which indicates that when subjects are forced to access a phonological representation of a word, they are more prone to phonological interference effects.

Siegel and Linder (1984) tested a group of reading-disabled and normally-reading children aged 7-13 years, and showed that the phonological interference effect occurred in the written and oral responses to both print and auditory stimuli, displaying a similar developmental lag pattern in reading-disabled participants as in Olson, et al. (1984). Seven- and 8-year-old reading disabled children did not show a difference in recalling rhyming versus non-rhyming materials, while older reading-disabled children, as well as reading-normal children of all ages, successfully recalled more non-rhyming than rhyming items. The magnitude of the difference between correct responses on rhyming and non-rhyming items decreased between ages 9-10 and 11-13 in normally-reading children, but increased between reading-disabled children in the same age groups. The study did not track reading-disabled children over the age of 13, but based on its findings, a logical hypothesis is that those children would perform better in non-rhyming trials than rhyming ones, and that the magnitude of the difference between the two types of trials would be less than that for younger reading-disabled children.

The three studies referenced above demonstrate that an interference effect for the recall phonologically-similar material occurs in a slightly older age group, for both print and auditory stimuli. In this project, we attempt to determine whether such an interference effect occurs for auditory stimuli by including both rhyming and non-rhyming materials in the pseudoword repetition task. Our target populations, three- and four-year-olds and 16- to 24-year-olds, both fall outside the developmental window observed in previous studies, so the presence or absence of an interference effect will contribute to knowledge about the developmental course of this phenomenon.

As established earlier, both phonological awareness and verbal working memory correlate strongly with subsequent reading success. Additionally, given the interference effect for phonologically-similar material established in the four preceding paragraphs, there is a clear link between phonological skills and phonological working memory capacity. It would be useful, then, to chart the developmental path of phonologically-grounded capacities. The current project helps to lay the groundwork for a proposed longitudinal study tracking these capacities by developing a pseudoword repetition task, suitable for preschool-aged children, to measure phonological working memory. In the proposed study, the pseudoword repetition task developed in the current project will be combined with a battery of other tasks to assess participants' phonological skills at developmentally salient intervals.

Overview of Current Project

This project is composed of two separate implementations of the pseudoword repetition task. In Experiment 1, we implement a preschooler-friendly adaptation of the pseudoword repetition task in combination with the phonological awareness subtest of the Test of Preschool Early Literacy (Lonigan, Wagner, & Torgesen, 2007) to probe the development of and relationship between verbal working memory and phonological awareness in three- and four-year-olds. In Experiment 2, we implement an adaptation of the pseudoword repetition task suitable for young adults (16- to 24-years-old) as part of a large battery of measures assessing reading comprehension, IQ, and other cognitive skills associated with reading. For the purposes of this project, we will be most closely examining the relationship between verbal working memory (as assessed by our pseudoword repetition task) and other measures of memory and phonological awareness in this population. For this older population, one important assessment of phonologically grounded capacities will be the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Togresen, and Rashotte [1999]). TOPEL was designed by the same authors as CTOPP and serves as a downward extension of the latter standardized test for use with younger populations. Across the two experiments, the same materials were used for the pseudoword repetition tasks, although the methods of presenting the materials and eliciting responses were necessarily different. The similarity between TOPEL and CTOPP and the fact that both standardized tests are extensively documented mean that they will serve as good comparison points for our experimental pseudoword repetition tasks.

<u>Development of Materials for the Pseudoword Repetition Tasks</u>

The same stimuli are used with the three- and four-year-old cohort and the 16- to 24-year-old cohort. Stimuli for this project are based on monosyllabic English pseudowords (i.e. wordlike segments which fit the phonotactic constraints of English but do not have meaning) found in the ARC Nonword Database (Rastle, Harrington, & Coltheart, 2002). Stimulus items are composed of trochees made of a monosyllabic pseudoword retrieved from the ARC database paired with a

CV syllable with a phonologically-conditioned onset and a lax vowel. Rhyming items are composed of trochees which differ only in the onset of the strong syllable, while non-rhyming items have strong syllables from different rhyme families. Table 1 illustrates the first three items each of the rhyme condition, at left, and the non-rhyme condition, at right, and shows that items are matched across conditions on neighborhood statistics:

Table 1 – Two-trochee pseudowords and neighborhood statistics for strong syllables

Table 1.a – Rhyming items				Table 1.b – Non-rhyming items			
English Gloss		Neighborhood Size	Neighborhood Frequency	English Gloss		Neighborhood Size	Neighborhood Frequency
BOAG	zuh	16	1157	MOIT	suh	14	1222
HOAG	zuh	14	1747	TAVE	duh	15	1773
PIFE	puh	15	937	WEEG	zuh	15	812
DIFE	puh	17	1018	FOOM	zuh	17	980
TEEV	buh	17	646	BOACH	tuh	17	685
KEEV	buh	18	802	DAPE	suh	18	874

Note: Line breaks separate items

In this table, "BOAG-zuh-HOAG-zuh" is a rhyming item two trochees long, and "MOIT-suh-TAVE-duh" is the corresponding non-rhyming item two trochees long. For the pseudoword repetition task, there are also six introductory items: three singleton pseudoword syllables and three singleton trochaic feet. These items are used for practice when (especially younger) participants struggle to recall the initial rhyming or non-rhyming items, or when (especially younger) participants are reluctant to engage in the task.

Pseudoword recall is greatly influenced by the degree to which pseudowords resemble real words (Gathercole 1995; Treiman, Goswami, and Bruck, 1990). Therefore, we were careful to balance the wordlikeness of pseudowords across rhyme conditions. The ARC Nonword Database includes information about each pseudoword's phonological neighbors (i.e. those real words which differ from the pseudoword by exactly one phoneme), based on data found in the CELEX English database (Rastle, Harrington, and Coltheart, 2002). Treiman, Goswami, and

Bruck (1990) demonstrated that rhyme neighborhood size affects pseudoword recall. For this study, we matched the items on the size of the phonological neighborhood (i.e. number of neighbors) and on the summed frequencies of those phonological neighbors. To do this, we paired the items in each list of one rhyme condition at a given length with the items of a partner list of the opposite condition at the same length. We also constrained the neighborhood size for all items to be between 5 and 20 neighbors and the summed frequency of phonological neighbors to be between 50 and 2000 occurrences. Table 1 shows neighborhood statistics for a rhyming and a non-rhyming family, each two trochees long.

Overall, T-tests reveal no significant difference in neighborhood size for rhyming and non-rhyming items, and no significant difference in summed frequency of phonological neighbors for rhyming and non-rhyming items. A full list of the stimuli used in this project, as well as complete statistics about their phonological neighborhoods and the summed frequencies of their phonological neighbors, can be found in Appendix A.

In addition to the wordlikeness characteristics described above, we imposed phonological constraints on the strong syllables selected for pseudoword repetition materials. Because this task is designed for use with young children (three- and four-year-olds), it was desirable to consider the perceptual salience and articulatory difficulty of our stimuli. We therefore excluded pseudowords containing lax vowels or cluster codas. Further, because some phonemes are mastered later than others, we excluded onset clusters and those phonemes identified by Schriberg and Kwiatkowski (1994) as the "Late Eight" consonants (i.e., /s/, /z/, /l/, /ɹ/, /ʃ/, /ʒ/, /θ/, /ð/) from items of three or fewer trochees. Onset clusters and late-developing phonemes were allowed in items beyond three trochees in lengths because the ability to produce these phonemes develops around the end of infancy. Although our target participants include three- and four-year-olds, only the youngest should be affected by these articulatory difficulties. Presumably, participants young enough to encounter these difficulties would fail on this task before they reach these articulatorily-more-difficult items (four trochees and longer) as a result of their less-developed verbal working memory skills.

As noted above, the same materials were used in Experiment 1 (three- and four-year-olds) and Experiment 2 (16- to 24-year-olds). The protocol for presentation and response elicitation differed for the two experiments as described in the *Methods* sections of the two experiments, below.

Experiment 1: Phonologically-Grounded Capacities in 3- and 4-Year-Olds

The goal of Experiment 1 was to investigate the relationship between phonological working memory (assessed with our experimental pseudoword repetition task) and phonological awareness (assessed with the phonological awareness subtest of the Test of Preschool Early Literacy; Lonigan, Wagner, & Torgesen, 2007) in prereading children ages 3 and 4.

Pilot Work

Development of a procedure suitable for use with young children began with pseudoword materials borrowed from Dollaghan and Campbell (1998). The initial procedure was based around a single experimenter (the author) helping Glerk the Space Chicken (see picture in Appendix B) teach the participant new space words in the waiting area/play room of the lab. After five participants, the newly developed pseudoword materials described above were plugged into the procedure. Further pilot work with those materials resulted in the refined protocol described in the *Methods* section, below. In total, 15 children participated in the pilot phase of this project. The pilot work demonstrated that children of our target age group are able to handle a pseudoword repetition task, as there was enough variance in the data to likely reflect individual differences.

Participants

Participants (N= 23, mean = 44.3 months, SD = 5.6, min = 37, max = 56; 12 girls) were recruited through Haskins Laboratories' Child Language Studies lab, which maintains a database of Connecticut birth records provided by the state Department of Health. One participant (female, age 41 months) was excluded due to noncompliance; additionally, some participants failed to complete all portions of both the pseudoword repetition task and the TOPEL phonological awareness assessment. Participants' parents were briefed on the protocol, and their signed consent was obtained for their children to participate in the study. All protocols were approved by the Yale Human Investigation Committee.

Methods

The protocol for the preschool cohort included two tasks: the phonological awareness subtest of TOPEL, and the experimental pseudoword repetition task developed for this project. For the preschool participants, the protocol needed to be interactive and engaging to maintain the participants' interest. To accomplish this goal, we developed a game involving two experimenters, a stuffed animal named Glerk the Space Chicken, and the participant. In the first phase of the session, the TOPEL phonological awareness subtest is administered. The lead experimenter (the author) engages the participant in the word games that make up the TOPEL phonological awareness assessment, while the second experimenter acts as a puppeteer and has Glerk the Space Chicken cheer on the participant whenever the participant gives a response to a TOPEL task item. Glerk cheers whether or not the participant answers the task item correctly, and his cheerleading is the only way in which TOPEL administration differs from the standard administration procedure. (See TOPEL Examiner's Manual, Lonigan, Wagner, Torgesen, and Rashotte, 2007, for details.) The TOPEL phonological awareness assessment comprises four tasks: an elision task in which the participant responds by pointing to the picture corresponding to the word formed by the elision, an elision task in which the participant responds verbally, a blending task in which the participant responds by pointing to a picture, and a blending task in which the participant responds verbally. Because the TOPEL phonological awareness assessment begins with a task with a non-verbal response, it is helpful in encouraging shy preschoolers to engage in the protocol. Since Glerk also cheerleads for the participant during TOPEL administration, he can build up a rapport with the participant that helps the second phase of the protocol to run smoothly.

The second phase of the protocol for the preschool cohort is the pseudoword repetition task. The lead experimenter serves as Glerk's translator, while the second experimenter serves as Glerk's puppeteer and voice. Glerk is a recent arrival from a faraway planet who is seeking to make some friends on Earth, but he doesn't speak English, so the translator must help Glerk teach the participant some of Glerk's words. The translator introduces the pseudoword, the puppeteer helps Glerk to say the pseudoword, and the translator then asks the participant to repeat the pseudoword, so the participant has heard the pseudoword three times before responding. The translator and the puppeteer both attempt to maintain eye contact when demonstrating target pseudowords for the participant, so that the participant may attempt to include information from the visual domain in their phonological representation of the target. A script of this interaction can be found in Appendix B: Protocol for Experiment 1. Participant's responses are judged correct if and only if the onset consonant (in some cases, onset consonant cluster) of the stressed syllable of every trochaic foot of the item is recalled correctly. The cutoff conditions are that after three consecutive recall failures in a rhyme condition, that condition is no longer presented, and the trial is terminated when the participant reaches the cutoff criterion in both the rhyming and non-rhyming conditions.

Results and Discussion

In addition to task scores, the following data were collected: ages and genders. From the pseudoword repetition task, we collected scores for rhyming items correct, scores for non-rhyming items correct, the total of correct responses, and the difference of scores on rhyming and non-rhyming items. From the Test of Preschool Early Literacy, we collected scores on each of the four subtests, the sum of scores on the blending tasks, the sum of scores on the elision tasks, the sum of scores on the pointing-response tasks, the sum of scores on the verbal-response tasks, the composite phonological awareness score, and, using conversion tables found in the TOPEL Examiner's Manual (Lonigan, Wagner, Torgesen, & Rashotte, 2007), a standardized phonological awareness score, which is related to children's percentile ranks on the phonological awareness subtest of TOPEL. Table 2, below, gives summary statistics for these data:

Table 2 – Summary of child data

Task Type	Measure	Mean	SD	Max possible
	Age (months)	44.30	5.55	--
Memory	Pseudoword Repetition total	6.05	2.82	30
	-- rhyme	2.90	1.71	15
	-- non-rhyme	3.15	1.46	15
PA	TOPEL PA composite	14.67	5.04	27
	--blending tasks	6.60	2.44	12
	--elision tasks	9.59	3.08	15
	--pointing responses	9.95	1.99	12
	--verbal responses	5.82	3.57	15

In this experiment, we sought to investigate the relationship between rhyming and non-rhyming scores, and the relationship between pseudoword repetition and phonological awareness tasks. We will examine the statistical relationships between various tasks and component tasks for the remainder of this section. Table 3, below, displays coefficients of correlation and P-values for the relationships between children's component and total scores on the pseudoword repetition task (showing scores for rhyming items, non-rhyming items, the sum of rhyming and non-rhyming, and the difference between rhyming and non-rhyming), and on the Phonological Awareness subtest of the Test of Preschool Early Literacy (showing composite score, standardized score, and scores for blending and elision tasks and pointing and verbal responses). Due to participants' varying compliance, sample sizes for these correlations range between 15 and 21. In this table, coefficients of correlation appear in the lower triangle, and P-values appear in the upper triangle. Statistically significant correlations ($p \leq .05$) are made bold and italic:

Table 3 -- Correlations among children's scores

1	Age	--	.1390	.1455	.0952	.7898	***.0427***	.7769	.3342	.1193	.1001	.2053
2	Pseudoword repetition: rhyming items	.34	--	***.0081***	***<.0001***	***.0061***	***.0148***	.1328	.2099	.0696	.2197	***.0481***
3	Pseudoword repetition: non-rhyming items	.34	***.57***	--	***<.0001***	.1662	***.0090***	***.0271***	.1225	***.0135***	.3885	***.0070***
4	Pseudoword repetition: all items	.38	***.91***	***.87***	--	.4172	***.0028***	***.0283***	.0979	***.0100***	.2203	***.0047***
5	Rhyming minus non-rhyming	.06	***.59***	-.32	.19	--	.6841	.9654	.8685	.9317	.5560	.9176
6	Phonological Awareness: composite (TOPEL)	***.45***	***.55***	***.58***	***.65***	.10	--	***<.0001***	***.0003***	***<.0001***	***.0007***	***<.0001***
7	Phonological Awareness: standardized (TOPEL)	-.07	.38	***.53***	***.53***	-.01	***.87***	--	***.0017***	***.0006***	***.0254***	***<.0001***
8	Blending tasks (TOPEL)	.27	.34	.42	.44	.05	***.81***	***.74***	--	.1034	***.0005***	***.0113***
9	Elision tasks (TOPEL)	.39	.45	***.59***	***.61***	.02	***.88***	***.75***	.44	--	.0757	***<.0001***
10	Pointing responses (TOPEL)	.37	.30	.21	.29	.14	***.68***	***.54***	***.79***	.44	--	.1864
11	Verbal responses (TOPEL)	.32	***.49***	***.63***	***.65***	.03	***.92***	***.83***	***.63***	***.89***	.34	--
		1	2	3	4	5	6	7	8	9	10	11

To investigate the potential presence of an interference pattern similar to that found in primary school children as documented by Mark, et al., 1977, Olson, et al., 1984, and Siegel and Linder, 1984, we performed a paired T-test on participants' scores on rhyming and non-rhyming items. This test revealed no significant difference (p = .46) between the rhyming and non-rhyming scores. This indicates that the interference pattern documented in the above studies likely does not extend downward into this younger population.

Standardized TOPEL score and score on elision tasks of TOPEL both displayed differentially significant correlations with rhyming and non-rhyming scores. Fischer's Z-test revealed no significant difference between either pair of correlations. This result is consistent with the non-significant outcome of the paired T-test above, and indicates that participants performed nearly identically on rhyming and non-rhyming items. This is further confirmed by the absence of any significant correlations between any phonological awareness scores and the difference of rhyming and non-rhyming item scores.

Age had a significant correlation with composite TOPEL score (r = .45, p = .0427) and a near-significant relationship with pseudoword repetition task total score (r = .38, p = .0952). As mentioned above, there was a significant correlation between TOPEL composite score and pseudoword repetition task score (r = .65, p = .0027). Given the correlation between age and TOPEL composite score and the near correlation between age and pseudoword repetition score, it would be useful to determine whether the correlation between the two tasks is due to age or exists independently of age. (i.e., Do participants happen to get better at both as they get older, or does getting better at one correspond with getting better at the other, regardless of age?).

To investigate this question, we regressed age from each measure and its component scores, and then examined the correlations among these age-partialed scores. Table 4, below, shows age-partialed correlations for the relationships between children's performance on the various tasks. Coefficients of correlation appear in the lower triangle, and the P-values for those relationships appear in the upper triangle. Statistically significant correlations ($p \leq .05$) are made bold and italic:

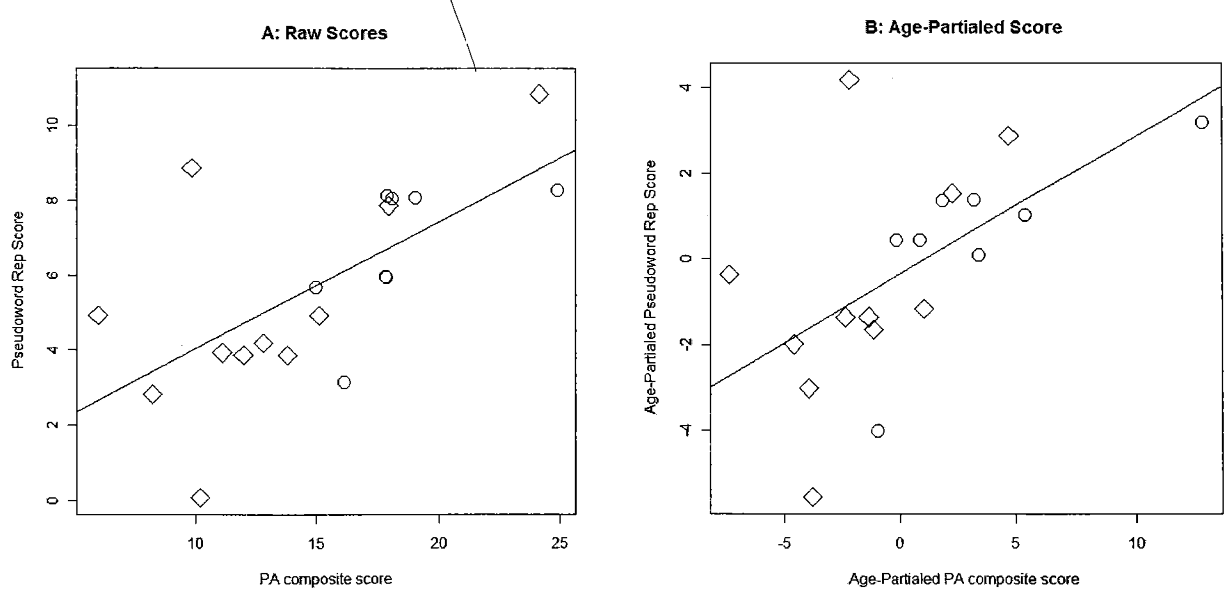
Tables 4 – Age-partialed correlations among children's scores

1	Age	--										
2	Pseudoword repetition: rhyming items	.00	--	***.0193***	***<.0001***	***.0046***	***.0357***	.0967	.2907	.1289	.4327	.0831
3	Pseudoword repetition: non-rhyming items	.00	***.52***	--	***<.0001***	.1128	***.0205***	***.0160***	.1816	***.0285***	.6891	***.0141***
4	Pseudoword repetition: all items	.00	***.89***	***.85***	--	.4426	***.0085***	***.0136***	.1552	***.0253***	.4750	***.0108***
5	Rhyming minus non-rhyming	.00	***.61***	-.37	.18	--	.7806	.9818	.9165	.9798	.6237	.9884
6	Phonological Awareness: composite (TOPEL)	.00	***.48***	***.53***	***.59***	.07	--	***<.0001***	***.0006***	***<.0001***	***.0026***	***<.0001***
7	Phonological Awareness: standardized (TOPEL)	.00	.42	***.57***	***.59***	-.01	***.99***	--	***.0004***	***<.0001***	***.0078***	***<.0001***
8	Blending tasks (TOPEL)	.00	.29	.36	.39	.03	***.78***	***.79***	--	.1704	***.0007***	***.0178***
9	Elision tasks (TOPEL)	.00	.38	***.53***	***.54***	-.01	***.85***	***.85***	.37	--	.1834	***<.0001***
10	Pointing responses (TOPEL)	.00	.19	.10	.17	.12	***.62***	***.62***	***.77***	.34	--	.3544
11	Verbal responses (TOPEL)	.00	.43	***.58***	***.60***	.00	***.91***	***.90***	***.60***	***.88***	.24	--
		1	2	3	4	5	6	7	8	9	10	11

From this table, we note that the correlation between phonological awareness composite score and pseudoword repetition task score is still significant ($r = .59$, $p = .009$). Since the standardized phonological awareness score has already attempted to account for age, composite and standardized phonological awareness scores are now almost identical ($r = .99$, $p < .0001$). We also observe that participants' scores on non-rhyming items have significant correlations with composite and standardized phonological awareness scores, and composite elision task scores, while rhyme item score does not significantly correlate with these task scores. While there are no significant differences in these pairs of correlations, this trend may lend some support to the hypothesis that non-rhyming pseudoword repetition is more phonologically demanding than rhyming pseudoword repetition.

The figure below shows the relationships between children's total scores on the pseudoword repetition task and the phonological awareness subtest of the Test of Preschool Early Literacy. The right panel shows the relationship between age-partialed total scores on these tasks. In the plots, diamonds represent males and circles represent females:

Figure 1 – Pseudoword Repetition Scores vs TOPEL Phonological Awareness Scores



Note: In these plots, diamonds represent males and circles represent females. Lines represent lines of best fit.

From these plots, we can see that there is a close relationship between pseudoword repetition score and TOPEL phonological awareness assessment score. The correlation for this relationship is .65 ($p = .0028$); the correlation for age-partialed scores is .59 ($p = .0085$). This indicates that some degree of phonological processing skill is implicated in pseudoword repetition. We can also examine the relative contributions of age and TOPEL phonological awareness score with a multiple regression of pseudoword repetition score on age and TOPEL phonological awareness score. The results of this regression can be found in Table 5, below.

Table 5 – Multiple regression of pseudoword repetition score

Predictor	Std. β	*T*	*P*	Unique R^2
Age	.01225	0.366	.0952	.005
PA	.57514	2.883	.0108	.275

Note: Unique R^2 is the proportion of variance captured by a given variable after taking into account all other predictors in the model; multiple $R^2 = .4216$.

From this table, we observe that phonological awareness score uniquely accounted for 27% of variance in pseudoword repetition score, and age uniquely accounted for 0.5% of variance in pseudoword repetition score. Since the model accounted for 42% of the variance in pseudoword repetition score, 14.5% of variance was shared. Phonological awareness score was the only significant term; age only reached near-significance. From this, we conclude that in three- and four-year-olds, phonological processing skill is implicated in pseudoword recall.

Experiment 2: Phonologically-Grounded Capacities in Young Adults

A version of the pseudoword repetition task described above was adapted for use in an ongoing study of literacy-related skills in young adults (16 to 24 years old). Participants' scores on the pseudoword repetition task will be compared to their score on measures of phonological awareness, phonological and visuospatial working memory, and IQ. Several other tasks, including the Peabody Picture Vocabulary Test, Test of Word Reading Efficiency, and Peabody Individual Achievement Test-Revised standardized tests are also administered over the three days in which young adults participate in the study; however, for our investigation of phonological working memory and phonological awareness, we will constrain our discussion to the tasks described in the *Methods* section, below.

Participants

Participants (N = 33; mean age = 19.78 years, SD = 2.41, max = 24.98, min = 16.31; 13 males) are recruited from the Greater New Haven area. The study targeted young adults, age 16- to 24-years-old, whose literacy skills limit future occupational prospects. Participants (or their parents, when participants were under 18 years old) provided written consent before any tasks were administered. All protocols were approved by the Yale Human Investigation Committee. Participants were paid for completing these protocols and others not included here.

Methods

The same stimuli are used for the adult cohort as for the preschool cohort in Experiment 1. See the *Materials for Pseuodoword Repetition Tasks* section, above, and Appendix A, below, for details on the stimuli for this experiment. For this experiment, stimuli were digitally recorded in a female voice. The participant listens to each stimulus item through headphones, then attempts to recall it to the experimenter. The task has the same correctness and failure-cutoff criteria as described in Experiment 1: Participant's responses are judged correct if and only if the onset of the stressed syllable of every trochaic foot is recalled correctly; after three consecutive recall failures in a rhyme condition, that condition is no longer presented, and the trial is terminated when the participant reaches the cutoff criterion for both rhyming and non-rhyming conditions.

The phonological awareness assessment for this experiment is the phonological awareness subtest of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, Rashotte, 1999). CTOPP was created by the same authors as TOPEL, and TOPEL serves as a downward extension of CTOPP for use with younger populations. Structurally, the two are very similar: like the phonological awareness composite score from TOPEL, the CTOPP phonological awareness score is based on elision and blending tasks; however, for CTOPP, all responses are verbal.

The memory assessments for this experiment (besides our experimental pseudoword repetition task) are the digit span subtest of CTOPP, the nonword repetition subtest of CTOPP, a sentence span task, and an adaptation of the Corsi blocks nonverbal memory task. In the CTOPP digit span task, participants repeat back increasingly long strings of randomized digits. The sentence span task is derived from the listening span task of Daneman and Carpenter (1980). Our task shares its architecture and protocol with the aforementioned listening span task, but for this project there are new (and more) materials. In this task, participants hear sentences, judge their truth or falsity, and after a certain (slowly increasing) number of sentences, are asked to repeat back the final word of each sentence since they last recalled sentence-final words. Our non-phonological memory assessment is an adaptation of the Corsi Blocks task (Corkin, 1974), a test of visuospatial working memory in which participants point to indicate a sequence of spatial locations that has been demonstrated by the experimenter.

The IQ assessment for this experiment is the Wechsler Abbreviated Scales of Intelligence (Wechsler, 1999). All testing was carried out by an experienced experimenter. Though several other tasks are also administered over the three days in which young adults participate in the study, for our investigation of phonological working memory and phonological awareness, we will constrain our discussion to the tasks described above.

Results and Discussion

This project investigates relationships between the pseudoword repetition task and tasks of visuospatial and phonological working memory, phonological awareness, and IQ, outlined in the *Methods* section of Experiment 2, above. Table 6 provides a summary of the data collected.

Table 6 – Summary of young adult data

Task Type	Measure	Mean	SD	Max Possible
	Age	19.78	2.41	--
Memory	Pseudoword Repetition total	12.15	3.04	30
	--Rhyming items	6.06	1.90	15
	--Non-rhyming items	6.09	1.55	15
	CTOPP Digit Span	17.03	3.24	21
	CTOPP Nonword Repetition	9.45	2.24	18
	Sentence Span	39.91	10.70	60
	Corsi Nonverbal Memory	4.62	1.16	9
PA	CTOPP Phonological Awareness	88.19	20.81	40
	--Blending tasks	13.55	4.96	20
	--Elision tasks	13.91	5.66	20
IQ	WASI-IQ	94.45	23.25	--

In this experiment, we sought to investigate the relationship between rhyming and non-rhyming scores, and the relationship between our experimental pseudoword repetition task and tasks of (phonological and non-phonological) working memory and phonological awareness. We will examine the statistical relationships between various tasks and component tasks for the remainder of this section.

Table 7 displays the coefficients of correlation between young adults' scores on pseudoword repetition (for rhyming items, non-rhyming items, and all items), sentence span, the digit span subtest of Comprehensive Test of Phonological Processing (CTOPP), the nonword repetition subtest of CTOPP, the phonological awareness composite of CTOPP (composed of blending and elision tasks), an adaptation of the Corsi nonverbal memory task, and the Wechsler Abbreviated Scales of Intelligences IQ test. Due to a few incomplete observations, sample sizes are different for different correlations. Statistically significant correlations ($p \leq .05$) have been made bold and italic.

Table 7 – Correlations in Young Adults' Scores

1	Age	--	.2998	.9970	.5177	.2369	.3377	.4200	.5045	***.0344***	.1668	.7554	.2616	.2454
2	Pseudoword Repetition: Rhyme	.19	--	***.0009***	***<.0001***	***.0001***	.0745	.0814	.0599	***<.0001***	.7427	***.0365***	.4849	.2662
3	Pseudoword Repetition: Non-rhyme	.00	***.55***	--	***<.0001***	.0882	***.0297***	.0782	***.0237***	***.0003***	.0681	.0874	.3471	.2681
4	Pseudoword Repetition: All	.12	***.91***	***.85***	--	.1764	***.0253***	***.0454***	***.0187***	***<.0001***	.2627	***.0281***	.3717	.2067
5	Rhyme minus Non-rhyme	.21	***.63***	-.30	.24	--	.9546	.7294	.9430	.2180	.1964	.4491	.9353	.8118
6	CTOPP: Phonological Awareness	.18	.32	***.38***	***.40***	.01	--	***<.0001***	***<.0001***	***.0062***	***.0244***	***<.0001***	.0863	***<.0001***
7	CTOPP: Blending	.15	.31	.31	***.35***	.06	***.84***	--	***.0005***	.0515	***.0034***	***<.0001***	***.0152***	***<.0001***
8	CTOPP: Elision	.12	.33	***.39***	***.41***	.01	***.89***	***.57***	--	***.0072***	.1564	***.0003***	.3893	***.0005***
9	CTOPP: Digit Span	***.37***	***.67***	***.59***	***.72***	.22	***.47***	.34	***.46***	--	***.0158***	***.0107***	.9117	***.0213***
10	CTOPP: Non-word Repetition	.25	.06	.32	.20	-.23	***.40***	***.50***	.25	***.42***	--	.1899	.0836	***.0007***
11	Sentence Span	.06	***.37***	.30	***.38***	.14	***.81***	***.75***	***.59***	***.44***	.23	--	***.0265***	***<.0001***
12	Corsi nonverbal memory	-.27	-.17	-.23	-.22	.02	.40	***.55***	.21	.03	.41	***.51***	--	***.0010***
13	WASI: IQ	.21	.20	.20	.23	.04	***.76***	***.77***	***.57***	***.40***	***.56***	***.69***	***.69***	--
		1	2	3	4	5	6	7	8	9	10	11	12	13

A paired T-test of participants' scores on rhyming and non-rhyming items in the pseudoword repetition task reveals no significance ($p = .91$) in the differences between the sample means (difference in means = .0303); Fisher's Z-tests on correlations of phonological awareness or memory scores with rhyming or non-rhyming item score reveal no significant difference between correlations with rhyme core versus correlations with non-rhyme score. This indicates that participants performed equally well on rhyming and non-rhyming items, and therefore that the interference effect documented in Mark et al. 1977, Olson, et a., 1984, and Siegel and Linder, 1984, does not extend upward into this age group.

There was a significant correlation between participants' scores on the CTOPP phonological awareness assessment and the pseudoword repetition task ($r = .40$, $p = .0253$). This indicates that phonological processing skill plays a role in pseudoword repetition in 16- to 24-year-olds. There was also a significant correlations between participants' score on the CTOPP digit span task and the pseudoword repetition task ($r = .72$, $p < .0001$). The close correlation between these two measures of phonological working memory supports construct validity of the experimental pseudoword repetition task. Pseudoword repetition score was also strongly correlated with another measure of phonological working memory, sentence span ($r = .38$, $p = .0281$). Interestingly, pseudoword repetition score was not significantly correlated with CTOPP nonword repetition score, even though these tasks share the same basic architecture. This lack of correlation may have something to do with the phonological processing load of the different materials, as our task is highly correlated with the digit span task, which is thought to have the least phonological processing load of phonological working memory tasks. Interestingly, our task is not significantly correlated with the Corsi nonverbal working memory task. This supports the idea of distinct phonological and visuospatial working memory systems, as advocated in Baddeley, 1992, and elsewhere. Though none of the memory or phonological awareness measures were particularly strongly correlated with age (the closest had correlations of about .20 with p-values about .10), it will be instructive to regress age out of our data and see what happens to these correlations.

Table 8, below, shows age-partialed correlations between children's performance on various tasks. The upper triangle of this table shows P-values, and the lower triangle shows coefficients of correlation. Statistically significant correlations ($p \leq .05$) are made bold and italic:

Table 8 – Age-partialed correlations between young adults' scores

1	Age	--												
2	Pseudoword Repetition: Rhyme	.00	--	***.0007***	***<.0001***	***.0001***	.0997	.1030	.0728	***<.0001***	.9374	***.0386***	.5690	.3527
3	Pseudoword Repetition: Non-rhyme	.00	***.56***	--	***<.0001***	.0806	***.0249***	.0750	***.0226***	***.0001***	.0595	.0869	.3280	.2577
4	Pseudoword Repetition: All	.00	***.91***	***.86***	--	.2123	***.0297***	.0531	***.0216***	***<.0001***	.3198	***.0297***	.4054	.2471
5	Rhyme minus Non-rhyme	.00	***.62***	-.31	.22	--	.8540	.8558	.9430	.3846	.0913	.4793	.7741	.9956
6	CTOPP: Phonological Awareness	.00	.30	***.40***	***.38***	-.03	--	***<.0001***	***<.0001***	***.0103***	***.0350***	***<.0001***	.0921	***<.0001***
7	CTOPP: Blending	.00	.29	.31	.34	.03	***.84***	--	***.0006***	.0756	***.0048***	***<.0001***	***.0379***	***<.0001***
8	CTOPP: Elision	.00	.32	***.40***	***.40***	-.01	***.89***	***.57***	--	***.0087***	.1949	***.0003***	.4139	***.0006***
9	CTOPP: Digit Span	.00	***.66***	***.63***	***.73***	.16	***.45***	.31	***.45***	--	***.0386***	***.0085***	.6168	***.0426***
10	CTOPP: Non-word Repetition	.00	.01	.33	.18	-.30	***.37***	***.48***	.23	***.36***	--	.2029	***.0766***	***.0013***
11	Sentence Span	.00	***.36***	.30	***.38***	.13	***.81***	***.75***	***.59***	***.45***	.23	--	***.0436***	***<.0001***
12	Corsi nonverbal memory	.00	-.14	-.24	-.20	.07	.40	***.48***	.20	.12	***.42***	***.47***	--	***.0012***
13	WASI: IQ	.00	.17	.20	.21	.00	***.76***	***.77***	***.57***	***.36***	***.54***	***.69***	***.69***	--
		1	2	3	4	5	6	7	8	9	10	11	12	13

The age-partialed correlation table displays the same patterns of significant correlations as described above: pseudoword repetition was significantly correlated with digit span phonological awareness, and sentence span. There were no significant differences in correlations of any task with rhyming versus non-rhyming pseudoword items. This indicates that age did not play a large role in either phonological awareness or phonological working memory tasks. Figure 2 shows the relationship between young adults' scores on the pseudoword repetition task and the phonological awareness component of CTOPP. The right panel shows the relationships between age-partialed scores on these tasks. Males are represented by diamonds, and females by circles.

Figure 2 – Pseudoword Repetition scores vs Phonological Awareness scores

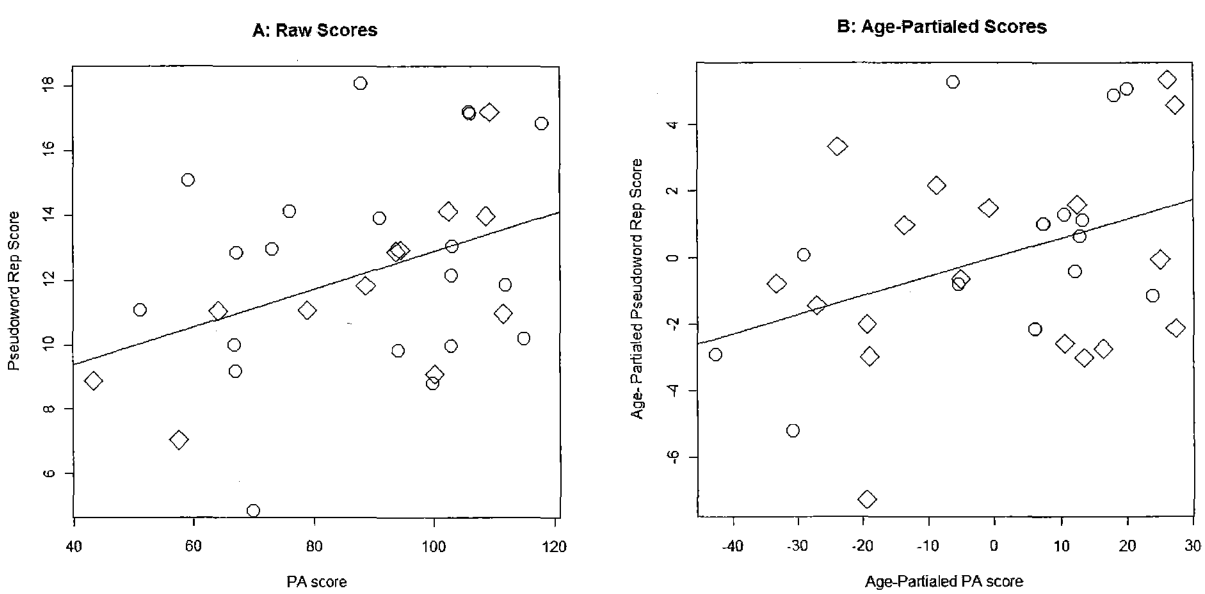


Figure 3 shows the relationship between young adults' scores on the pseudoword repetition task and the digit span subtest of CTOPP. The right panel shows the relationships between age-partialed scores on these tasks. Males are represented by diamonds, and females by circles.

Figure 3 – Pseudoword Repetition score vs CTOPP Digit Span score

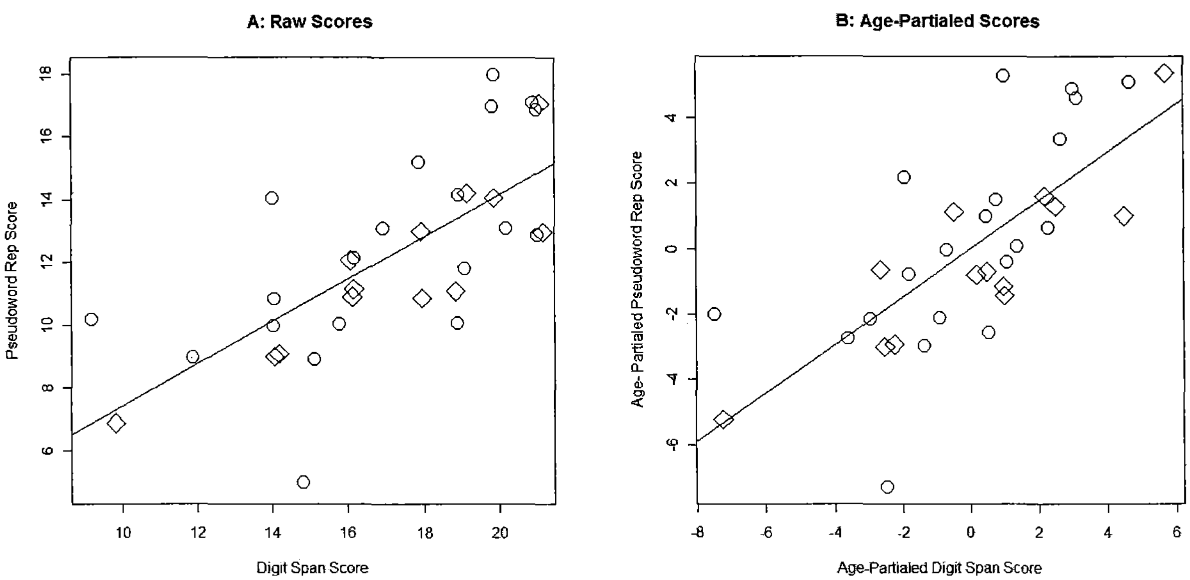
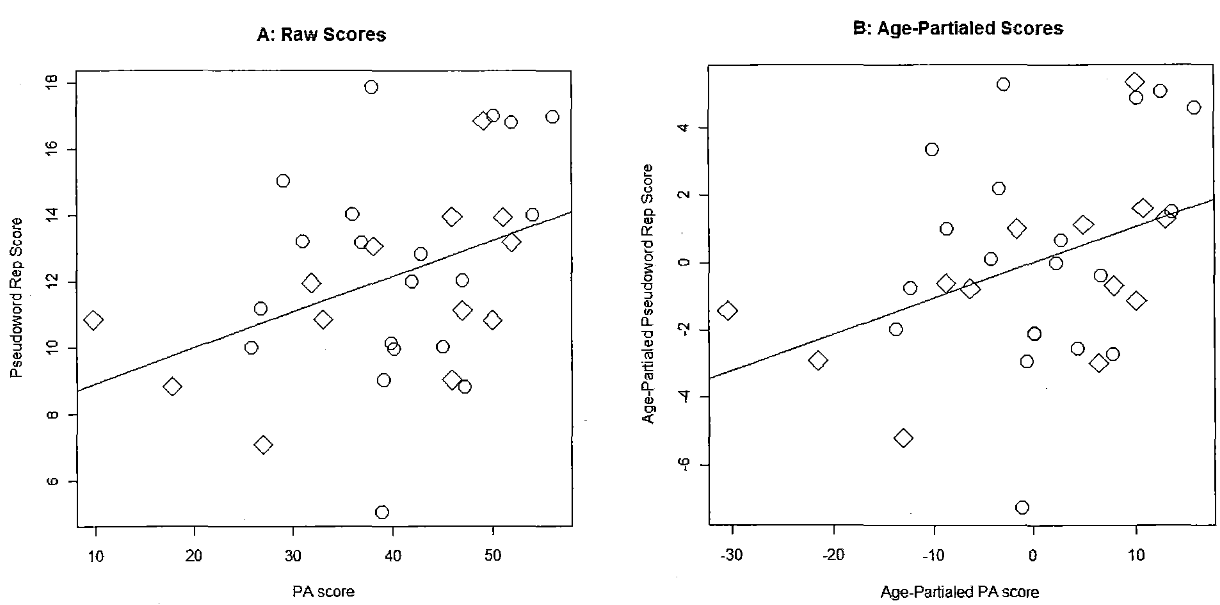


Figure 4 shows the relationship between young adults' scores on the pseudoword repetition task and the sentence span task. The right panel shows the relationships between age-partialed scores on these tasks. Males are represented by diamonds, and females by circles.

Figure 4 – Pseudoword Repetition scores vs Sentence Span scores



We can perform multiple regressions to determine the relative relationships of various tasks that are correlated with pseudoword repetition score. First, we perform a regression of pseudoword repetition score on age and all of the memory task scores with which it is correlated. Only Digit Span explains unique variance in this model (Model A). Next, we regress pseudoword repetition score on age, phonological awareness score, and the surviving memory measure from the previous regression (Model B). Table 9 shows the results of these models.

Table 9 – Multiple regression of pseudoword repetition score

	Predictor	Std. β	*T*	*P*	Unique R^2
Model A					
	Age	-0.0710	-1.286	.2080	.014
	Digit Span	0.8199	5.582	>.0001	.526
Model B					
	Age	-0.0765	-1.334	.1930	.011
	Digit Span	0.7485	4.980	>.0001	.388
	PA	0.0725	0.501	.6200	.004

Note: Unique R^2 is the proportion of variance captured by a given variable after taking into account all other predictors in the model. Model A, multiple R^2=.5394; Model B, multiple R^2=.5454. Digit span was the only measure to survive Model A.

Digit span is the only memory measure which survives the first multiple regression analysis. In Model A, it uniquely accounts for 53% of the variance in pseudoword repetition score. In Model B, there is one fewer sample because of a missing value for a CTOPP phonological awareness score, but digit span score is still the only significant term in the model, uniquely accounting for 39% of the variance in pseudoword repetition score. Phonological awareness score, the added term in model B, captures less than 1% of unique variance, indicating that most of the variance it accounts for is shared with digit span score. In Model B, the terms uniquely account for 40% of the variance, and the model accounts for 55% of the variance, meaning that 15% of the variance is shared. From Model B, we conclude that pseudoword repetition success is more closely linked to phonological working memory (as assessed by digit span) than to phonological awareness (as assessed by the CTOPP phonological awareness assessment).

General Discussion

In the two experiments described above, we had two main goals: first, to probe the relationship between phonological working memory (as assessed by the experimental pseudoword repetition task developed for this project) and other phonologically-grounded capacities, specifically phonological awareness and other measures of phonological working memory, and second, to probe for an interference effect for rhyming material similar to that documented in Mark, et al., 1977, Olson, et al., 1984, and Siegel and Linder, 1984. We examined these questions in three- and four-year-olds and in 16- to 24-year-olds.

First, we note that in both age groups, pseudoword repetition score was significantly correlated with phonological awareness. This indicates that phonological processing skill is implicated in pseudoword repetition, which makes sense, as pseudowords are phonologically complex material. The presence of this relationship in both age groups supports the construct validity of our experimental task. Second, we note that our experimental pseudoword repetition task was significantly correlated with other measures of phonological working memory in 16- to 24-year-olds. This finding further supports construct validity.

Third, we note that there were no significant differences between scores on rhyming and non-rhyming items in either age group. Both of our age groups were outside the range of ages demonstrated to exhibit the interference effect in Mark, et al. 1977, Olson, et al., 1984, and Siegel and Linder, 1984, who demonstrated the phenomenon in primary schoolers aged 7-16, with the effect size decreasing between 13 and 16 (Olson, et al., 1984). Our findings indicate that the interference affect appears between ages 4 and 7, and we confirm that the effect dissipates around the end of puberty.

Further Research

Based on the findings described above, there are two main areas in which this research could expand. First, future research could examine the relationship between phonological working memory and phonological awareness between 6 and 16 years of age. In our experiments, we found the correlation between the two to drop from .65 in preschool to .35 in young adulthood. We would expect to find correlations between these values at intermediate developmental stages. This trend would also be expected because, as Scarborough, 2005, and Catts, Hogan, and Adlof, 2005, note, these two skills' correlations with reading also changes over time. Second, future research could attempt to isolate the onset of phonological interference between 4 and 7 years of age, as the phenomenon did not occur in the preschoolers in our experiment, but has been demonstrated to exist in primary schoolers.

Appendix A – Experimental Pseudoword Repetition Materials and Neighborhood Statistics

In Table 10, rhyming items (at left) are paired with non-rhyming items (at right) and matched for neighborhood statistics. T-tests reveal no significant difference between neighborhood sizes ($T = -0.555$, $p = .58$) or summed frequencies of neighbors ($T = -0.022$, $p = .99$) for rhyming versus non-rhyming items. There were also no significant differences in neighborhood sizes or summed frequencies between rhyme conditions at any length, as shown in Table 11.

Table 10 – Neighborhood statistics for strong syllables in pseudoword repetition materials

Length	Condition	English Gloss	Neighborhood Size	Neighborhood Frequency	Length	Condition	English Gloss	Neighborhood Size	Neighborhood Frequency
0	NA	neem	20	1544					
0	NA	foun	18	1873					
0	NA	feep	19	1367					
1	NA	boap fuh	20	1119					
1	NA	hoach tuh	16	1789					
1	NA	thoot suh	14	1098					
2	r	boag zuh	16	1157	2	n	moit suh	14	1222
2	r	hoag zuh	14	1747	2	n	tave duh	15	1773
2	r	pife puh	15	937	2	n	weeg zuh	15	812
2	r	dife puh	17	1018	2	n	foom zuh	17	980
2	r	teev buh	17	646	2	n	boach tuh	17	685
2	r	keev buh	18	802	2	n	dape suh	18	874
3	r	choap fuh	17	727	3	n	noom zuh	16	640
3	r	goap fuh	18	924	3	n	toin zuh	19	961
3	r	boap fuh	20	1119	3	n	feep suh	19	1367

Length	Condition	English Gloss		Neighborhood Size	Neighborhood Frequency	Length	Condition	English Gloss		Neighborhood Size	Neighborhood Frequency
3	r	bive	buh	14	603	3	n	dafe	puh	15	607
3	r	give	buh	14	1618	3	n	poun	vuh	15	1616
3	r	pive	buh	16	622	3	n	cheem	vuh	16	743
3	r	deech	tuh	14	690	3	n	heef	puh	18	810
3	r	keech	tuh	20	737	3	n	boav	buh	13	649
3	r	neech	tuh	18	915	3	n	veek	fuh	19	811
4	r	sheev	buh	14	379	4	n	zoat	suh	12	376
4	r	deev	buh	14	727	4	n	deef	puh	15	528
4	r	neev	buh	16	985	4	n	goam	zuh	16	965
4	r	keev	buh	18	802	4	n	dape	suh	18	874
4	r	chape	fuh	15	530	4	n	wibe	zuh	14	693
4	r	hape	fuh	20	750	4	n	toop	fuh	18	743
4	r	trape	fuh	14	453	4	n	greep	fuh	16	469
4	r	stape	fuh	16	840	4	n	shoam	vuh	16	757
4	r	groun	vuh	14	184	4	n	krame	zuh	14	184
4	r	foun	vuh	18	1873	4	n	hoach	tuh	16	1789
4	r	roun	vuh	19	1872	4	n	thate	suh	16	1741
4	r	poun	vuh	15	1616	4	n	neem	zuh	20	1544
5	r	goom	zuh	16	444	5	n	foit	suh	14	406
5	r	choom	zuh	16	475	5	n	noach	tuh	14	481
5	r	kroom	zuh	13	111	5	n	freet	suh	13	117
5	r	shoom	zuh	16	438	5	n	roog	zuh	16	452
5	r	foom	zuh	17	980	5	n	boap	suh	20	1119

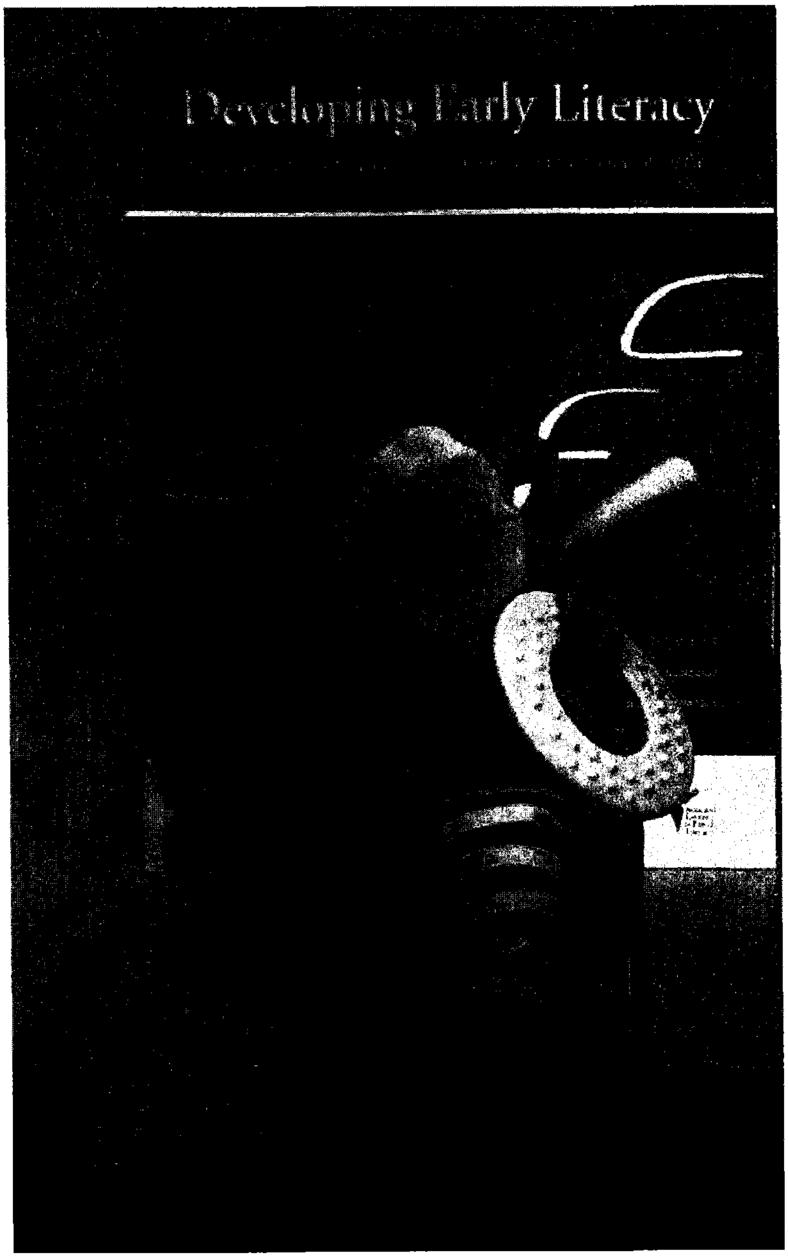
Length	Condition	English Gloss	Neighborhood Size	Neighborhood Frequency	Length	Condition	English Gloss	Neighborhood Size	Neighborhood Frequency
5	r	foab zuh	10	109	5	n	foop fuh	10	164
5	r	noab zuh	15	461	5	n	goak suh	16	469
5	r	koab zuh	16	286	5	n	peeb zuh	16	307
5	r	hoab zuh	14	1747	5	n	give buh	14	1618
5	r	groab zuh	13	153	5	n	spoat suh	13	174
5	r	gife puh	13	918	5	n	fibe vuh	11	814
5	r	bife puh	15	922	5	n	goam zuh	16	965
5	r	chife puh	12	927	5	n	feech tuh	13	1066
5	r	hife puh	15	1428	5	n	goav buh	14	1430
5	r	sife puh	20	1661	5	n	theet suh	17	1563
6	r	geem zuh	11	663	6	n	boaf puh	10	644
6	r	feem zuh	18	1891	6	n	foun vuh	18	1873
6	r	jeem zuh	16	647	6	n	sibe vuh	15	723
6	r	neem zuh	20	1544	6	n	feep fuh	19	1367
6	r	sheem zuh	17	701	6	n	choap fuh	17	727
6	r	cheem zuh	16	743	6	n	zeek suh	19	807
6	r	bipe fuh	15	295	6	n	hook suh	15	266
6	r	dipe fuh	16	428	6	n	fache tuh	14	310
6	r	nipe fuh	15	1295	6	n	mibe vuh	10	1144
6	r	kipe fuh	16	773	6	n	neef puh	16	764
6	r	shipe fuh	12	531	6	n	thoam zuh	12	546
6	r	mipe fuh	14	1439	6	n	mive buh	15	1935
6	r	gafe puh	16	399	6	n	teeg zuh	16	379
6	r	dafe puh	15	607	6	n	foap fuh	16	591
6	r	shafe puh	15	189	6	n	loog zuh	14	172
6	r	stafe puh	14	850	6	n	steet suh	14	838
6	r	kafe puh	17	1323	6	n	boag zuh	16	1157
6	r	grafe puh	13	1066	6	n	plame zuh	14	1002

Table 11 – Results of T-tests on rhyming vs non-rhyming items at each length

Length		*t*	*p*
2	Neighborhood Size	-0.1910	0.8523
2	Neighborhood Frequency	0.0289	0.9975
3	Neighborhood Size	-0.1019	0.9201
3	Neighborhood Frequency	0.1741	0.8640
4	Neighborhood Size	-0.1916	0.8498
4	Neighborhood Frequency	-0.1286	0.8988
5	Neighborhood Size	-0.3011	0.7655
5	Neighborhood Frequency	0.0291	0.9770
6	Neighborhood Size	-0.4253	0.6734
6	Neighborhood Frequency	-0.0477	0.9623

<u>Appendix B – Protocol for Experiment 1</u>

Figure 4 – Glerk the Space Chicken



Sample Pseudoword Repetition Script:

Translator: All right, [participant], you did a great job on our word games. Glerk thinks so, too – did you see how excited he was when you answered for us? [Puppeteer helps Glerk high-five the participant.] Well, [participant], I'd like to tell you a little more about Glerk. He's from outer space, from a planet far, far away. And on that planet, they speak a different language. Have you seen the TV show *Dora the Explorer*?

[Participant]: [usually yes]

Translator: Yeah, well you know how sometimes Dora says "Hola" instead of "Hello?" Do you know why she does that? It's because she's speaking another language – She's speaking Spanish. Well, Glerk speaks another language, too, but his language isn't Spanish, it's from outer space. Since Glerk just got here from outer space yesterday, and he doesn't speak any English, he's had a hard time making friends. He hopes that maybe I could help him teach you some of his outer space words so you can be friends. Would you like to make Glerk happy and be his friend?

[Participant]: Okay

Translator: Okay, well Glerk wants me to help him teach you his word for hello. It's "BOAG-zuh-HOAG-zuh." Let's let him say it.

Puppeteer: "BOAG-zuh-HOAG-zuh."

Translator: [Participant], can you say, "BOAG-zuh-HOAG-zuh?"

[Participant]: "BOAG-zuh-HOAG-zuh."

Translator: Yeah, very good. [Glerk cheers.] Look how happy Glerk is to hear you say hello in his language!

Glerk gives positive feedback whether the child successfully repeats the target pseudoword or not, and when the child fails at the first attempt, the translator demonstrates the word again and asks the participant to repeat it again.

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