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The Effects of Concurrent Cognitive Load on Phonological Processing in Adults Who Stutter

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Purpose: To determine whether phonological processing in adults who stutter (AWS) is disrupted by increased amounts of cognitive load in a concurrent attention-demanding task.
Method: Nine AWS and 9 adults who do not stutter (AWNS) participated. Using a dual-task paradigm, the authors presented word pairs for rhyme judgments and, concurrently, letter strings for memory recall. The rhyme judgment task manipulated rhyming type (rhyming/nonrhyming) and orthographic representation (similar/dissimilar). The memory recall task varied stimulus complexity (no letters, 3 letters, 5 letters). Rhyme judgment accuracy and reaction time (RT) were used to assess phonological processing, and letter recall accuracy was used to measure memory recall.
Results: For rhyme judgments, AWS were as accurate as AWNS, and the increase in the cognitive load did not affect rhyme judgment accuracy of either group. Significant group differences were found in RTs (delays by AWS were 241 ms greater). RTs of AWS were also slower in the most demanding rhyme condition and varied with the complexity of the memory task. Accuracy of letter recall of AWS was comparatively worse in the most demanding 5-letter condition.
Conclusion: Phonological and cognitive processing of AWS is more vulnerable to disruptions caused by increased amounts of cognitive load in concurrent attention-demanding tasks.

Key Words: stuttering, phonological processing, cognitive load, memory recall, reaction time

Since the 1940s, linguistic aspects of stuttering have been explored (e.g., Brown, 1945) and continue to receive considerable attention (for recent reviews, see Byrd, Wolk, & Davis, 2007; Hall, Wagovich, & Bernstein-Ratner, 2007; Ntourou, Conture, & Lipsey, 2011). Likewise, linguistic aspects of stuttering have been incorporated into theoretical models of stuttering (e.g., Conture et al., 2006; Perkins, Kent, & Curlee, 1991; Postma & Kolk, 1993), even though some have noted nonsignificant differences in speech-language abilities between children who stutter and those who do not (e.g., Hall et al., 2007; Nippold, 1990, 2001, 2002, 2004). Indeed, it has been suggested that people who stutter may not differ markedly from people who do not stutter in terms of clinically significant speech-language difficulties (measured by standardized tests) as much as they differ in more subtle aspects of speech-language processing—for example, elements of speech-language planning and production essential for rapid, efficient "real-time" production (e.g., Anderson & Conture, 2004; Byrd, Conture, & Ohde, 2007; Cuadrado & Weber-Fox, 2003; Hartfield & Conture, 2006; Pellowski & Conture, 2005). Kleinow and Smith's (2000) findings that increased linguistic complexity contributes to disruptions in the spatiotemporal stability of speech-motor control of adults who stutter (AWS) seem to support this assertion, as do similar findings with children who stutter (e.g., Zackheim & Conture, 2003).

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Phonological Processing

The present study focuses on phonological processing, a component that has been frequently studied in children who stutter (see Byrd, Wolk, & Davis, 2007, for a review). One factor that has motivated research in phonological processing in children is the observation that co-occurring phonological disorders occur at a higher rate in the population of children who stutter than in the general population (e.g., Blood, Ridenour, Qualls, & Hammer, 2003). Furthermore, children who stutter who also display delays in phonological development are more likely to exhibit persistent stuttering (Paden, Yairi, & Ambrose, 1999). Findings such as these, however, have been tempered by Nippold (2001, 2002, 2004), who argued that methodological approaches and rates of co-occurrence of stuttering and phonological disorders vary markedly, which emphasizes the need for further research. Thus, the apparent differences between children who stutter and those who do not have led to the continued assessment of sound-based or phonological abilities of the former (e.g., Anderson, Wagovich, & Hall, 2006; Coalson, 2008; Hakim & Ratner, 2004; Melnick, Conture, & Ohde, 2003; Weber-Fox, Spruill, Spencer, & Smith, 2008). For example, children who stutter were found to produce significantly fewer correct two- and three-syllable nonword repetitions and made significantly more phoneme errors on three-syllable nonwords as compared with children who do not stutter (Anderson et al., 2006). Children who stutter were also reported to display lower accuracy on rhyme judgments compared with children who do not stutter, which may be attributable to atypical neural processes related to the phonological encoding mediating rhyming decisions (Weber-Fox et al., 2008). Overall, children who stutter, compared with children who do not, exhibit salient deficits of phonological processing that may contribute to the onset and development of the disorder.

A formal account of how difficulties with phonological processing may contribute to stuttering—in both children and adults—admits the possibility that the disfluencies of individuals who stutter originate as a deficit of phonological encoding (Postma & Kolk, 1993; Kolk & Postma, 1997). For example, the *covert-repair hypothesis* (Postma & Kolk, 1993), which is based on Levelt, Roelofs, and Meyer's (1999) three-stage model of language production, proposes that the deficit occurs during the creation of the articulatory plan (i.e., the formulation stage). The proposed deficit of phonological encoding is thought to produce vulnerabilities of the phonetic plan, resulting in errors such as phonemic and phonetic distortions (Kolk & Postma, 1997). In turn, the high frequency of errors in the phonetic plan produces many opportunities for covert self-repair. Speech fluency is then disrupted when errors are detected through internal self-monitoring, and real-time covert repairs of the speech plan are attempted.

Yaruss and Conture (1996) empirically assessed the predictions of the covert-repair hypothesis in a group of nine boys who stuttered but exhibited normal phonology (3–6 years old) versus nine boys who stuttered and exhibited disordered phonology (3–6 years old). Predictions that speech disfluencies and speech errors would co-occur were supported for nonsystematic ("slip-of-the-tongue") errors but not systematic ("phonological process/rule-based") errors. However, the covert-repair hypothesis prediction that more speech disfluencies, or speech errors, would occur when speaking rate was faster or when shorter response-time latencies were present was not supported. Yaruss and Conture's (1996) findings suggested that speech disfluencies may represent self-repairs of nonsystematic speech errors; this suggestion, in turn, supports the possibility that phonological processing may be involved with stuttering.

In addition to Yaruss and Conture (1996), Weber-Fox, Spencer, Spruill, and Smith (2004) tested the predictions of the covert-repair hypothesis in the adult population using a rhyme judgment task that did not involve overt speech production. In this task, cognitive loads were varied via manipulation of the rhyme condition (i.e., rhyming or nonrhyming) and orthographical condition (i.e., similar or dissimilar). To make rhyme judgments of pairs of words (i.e., prime and target), Weber-Fox et al. (2004) posited that the participant must retrieve the phonological representation of the prime, hold it in working memory, segment it into its onset and rime elements (both phonological and orthographical information considered), and then make the rhyme judgment (Baddeley, 1986; Besner, 1987). Using event-related brain potentials (ERPs), Weber-Fox et al. (2004) reported no significant between-group differences in phonological encoding systems. However, based on reaction time (RT) measurements, it was suggested that for AWS, compared with adults who do not stutter (AWNS), the late stages of phonological processing were more vulnerable to increased cognitive loads and operate less efficiently (Weber-Fox et al., 2004).

The findings of Weber-Fox et al. (2004) motivated the present investigation of phonological processing in AWS. Specifically, cognitive loads in that study were shown to affect the efficacy of the phonological processing in adults only when the task demands were high. However, in this study, we varied the amounts of cognitive load in a single task and varied the combination of rhyme and orthographic representation. It could be the case that phonological processing in AWS is even more disturbed when such rhyme and orthography combinations are presented in a dual-task paradigm that imposes additional cognitive demands on the processing system.

Cognitive Load

The notion that the linguistic processes of people who stutter are more vulnerable to increased cognitive load is not novel. The disruptive effects of increased cognitive load on speech-language planning and production have been studied empirically in the stuttering population (e.g., Bosshardt, 2006; Caruso, Chodzko-Zajko, Bidinger, & Sommers, 1994). The differences in processing of cognitive load by these individuals are not thought to represent clinically significant cognitive delays or disorders.

Rather, it is suggested that the speech-language planning and production of people who stutter is more vulnerable to disruptions and disfluencies from increases in cognitive load.

Bosshardt, Ballmer, and De Nil (2002) directly assessed the effects of cognitive processing demands on AWS during single-task versus dual-task conditions and found that AWS display fewer propositions than AWNS during the dual-task condition. Bosshardt et al. (2002) interpreted their results as evidence that the organization of the speech production systems of AWS, when compared with those of AWNS, are more susceptible to disruptions caused by concurrent attention-demanding semantic tasks. In another study, Bosshardt (2002) measured the disfluencies of repeated words while the participants concurrently engaged in silent reading and word memorization tasks. Bosshardt (2002) found that AWS, compared with AWNS, exhibited increased disfluencies with increased attention-demanding coding and decision processes (cognitive processing loads). These findings were interpreted as supporting the notion that the "phonological and articulatory systems of people who stutter are more vulnerable to interference from attention-demanding processing tasks in the central executive" (p. 108). This interpretation is plausible and is consistent with other reports suggesting that speech production by AWS, compared with that of AWNS, is more vulnerable to increased disfluencies and temporal disruptions during highly stressful cognitive tasks (Caruso et al., 1994). More recently, Bosshardt (2006) summarized his empirical studies of the effects of cognitive processing load on stuttering and concluded that at least some people who stutter have a less "modularized" speech planning system, resulting in less effective protection from interference from concurrent activities in other parts of the cognitive system.

As already discussed, Weber-Fox et al. (2004) examined effects of varying levels of cognitive processing load on phonological processing through manipulation of rhyme and orthographic conditions with RT and accuracy measures. A robust difference between the AWS and AWNS was found for one condition, in which participants were to encode different phonological representations (nonrhyming words) from similar orthographic symbols. Although this condition was most cognitively taxing for all participants, AWS performed more poorly on both measures, albeit only significantly so on the RT measurement. Weber-Fox et al. (2004) suggested that AWS found it difficult to ignore information irrelevant to task performance (i.e., orthography), and, thus, processing accuracy and efficiency were compromised. Weber-Fox et al. (2004) interpreted significantly longer RTs as evidence that the phonological encoding of AWS was more vulnerable to interference from increased cognitive load. The findings of Weber-Fox et al. (2004) appear to be an important contribution toward the comprehensive account of the phonological processing of AWS. Given the importance of these findings, in the present study, we sought to replicate the results of Weber-Fox et al. (2004) by increasing cognitive load as an incremental modification to their original methodology. This modification was introduced to gain further insights, given other reports suggesting that speech production of AWS, compared with that of AWNS, is more vulnerable to increased disfluencies and temporal disruptions during highly stressful cognitive tasks (Caruso et al., 1994).

The Present Study

The present study was designed to gain a better understanding of how phonological processing in AWS may be affected by increased amounts of cognitive load in a task that employs concurrent attention-demanding conditions. Although it is the case that cognitive processing has been extensively studied in such dual-task paradigms, the effects of cognitive load on phonological processing were typically investigated in a single task, which manipulated interactions between phonological and nonphonological (e.g., orthographic) information.

Although several concurrent tasks (e.g., attention, linguistic, motoric) could be employed to increase cognitive load, a memory task was chosen as a suitable alternative for three reasons. First, there have been speculations that working memory may be involved in the disorder of stuttering (see Bajaj, 2007, for a review). Second, working memory has been shown to play an important role in phonological processing (for a review, see Baddeley, 2003). Third, the present memory task was easy to implement as (a) it was readily understood by participants and (b) it could be employed concurrently with the rhyme task used by Weber-Fox et al. (2004). It is possible that other concurrent tasks could be used in lieu of the memory task with similar results, but that remains to be shown in a separate investigation.

Even though the measurement of performance speed and accuracy has been used to assess the phonological processing of people who stutter (e.g., Melnick et al., 2003), the measures in the present study have been employed to assess somewhat different aspects of phonological processing. Specifically, the study's two dependent variables—speed and accuracy of rhyme-decision responses—were used to provide insights into the capacity for and actual use of phonological processing by AWS and AWNS during concurrent attention-demanding tasks. It was thought that assessing the processing capacity during dual-task conditions could serve as an experimental analogue for speech processing requirements during complex communicative situations. Indeed, research has shown that concurrent motoric, linguistic, and cognitive tasks influence speech-motor performance (e.g., Dromey & Benson, 2003), an effect that seems to influence AWS to a greater degree than it does AWNS (e.g., Kleinow & Smith, 2000). Ultimately, such differences in the speech-motor abilities of AWS may account for findings that AWS are more likely to stutter as processing loads increase via complexity (Caruso et al., 1994) or dual-task situations (Bosshardt, 2002). On the basis of this line of reasoning, it is possible that slower and more error-laden phonological processing during dual-task conditions for AWS, compared with AWNS, represent processing deficits that may in turn influence speech-motor performance and contribute to stuttering. Such findings would contribute to a comprehensive understanding of stuttering and would support accounts of stuttering that posit important contributions from processing load (Bosshardt, 2006).

In the present investigation of the additive effects of concurrent cognitive loads, the participants were required to process both phonological and orthographic information while attending to additional nonlexical stimuli. To determine the effects of the additional cognitive load on phonological processing, in the present experiment, we used the original rhyming paradigm in Weber-Fox et al. (2004) but presented their word pairs and additional stimuli (three- and five-letter combinations) under dual-task conditions. We expected this modification to increase the differences between the performance of AWS and AWNS. In particular, we expected the additional cognitive load to decrease the overall accuracy and speed of phonological processing of AWS compared with AWNS. We also expected that the increased cognitive load would negatively affect AWS's memory recall of the strings of letters presented concurrently with the rhyming words. The results contribute to a better understanding of processing abilities of AWS under real-time constraints. They are informative with regard to whether the phonological processing in AWS, when compared with that in AWNS, operates less efficiently during concurrent attention-demanding cognitive tasks, which are typically encountered in real-life situations.

Method

Participants

Participants were nine AWS and nine AWNS, all of whom were speakers of Standard American English and were matched for gender and educational background. As depicted in Table 1, participants were between ages 19 and 52 years (AWS: M = 32.33 years, SD = 12.00; AWNS: M = 32.33 years, SD = 12.13) with no statistically significant between-group difference in chronological age. From an initial group of 10 AWNS, one AWNS was excluded during data analysis because the participant's mean RT was not within 2 SDs of the mean for the designated talker group. All participants were paid volunteers naïve to the purpose and methods of the study. They were recruited using a printed advertisement/recruitment flyer distributed to (a) clinicians working with AWS at The Ohio State University Speech-Language-Hearing Clinic, (b) the clinic waiting room, and (c) members during a meeting of the National Stuttering Association. After written and verbal explanation of the study, all participants signed an informed consent. The institutional review board at The Ohio State University, Columbus, approved this study's protocol as well as the consent form.

Classification and inclusion criteria. An adult was considered an AWS if he or she (a) reported a history of diagnosed developmental stuttering that persisted into adulthood (i.e., onset during early childhood) and (b) received a total score of 9 or above (a severity equivalent of at least "very mild") on the Stuttering Severity Instrument for Children and Adults—Third Edition (SSI–3; Riley, 1994); see Table 1 for details. Each AWS reported a treatment history characterized by considerable variability in prior treatments, including differences in type of treatment, duration, and frequency. We are unaware of evidence that stuttering treatment influences the phonological processing of AWS, specifically during dual-task conditions; however, this possibility cannot be ruled out. An adult was considered an AWNS if he or she reported no history of developmental stuttering and no stuttering in adulthood.

Speech, language, hearing abilities, and visual acuity. As seen in Table 2, all participants scored at the 16th percentile or higher on at least three subtests of the Test of Adolescent and Adult Language—Third Edition (TOAL–3; Hammill, Brown, Larsen, & Wiederholt, 1994) and the Oral Speech Motor Examination—Revised (OSME–R; St. Louis & Ruscello, 1987). These standardized tests are used to assess language abilities and the structure and function of the oral speech mechanism. Participants also passed a bilateral pure-tone hearing screening (American Speech-Language-Hearing Association, 1990). No neurological, speech, language, or hearing impairments were reported by the participants, and all reported and demonstrated adequate visual acuity for task performance. These evaluations were made during each participant's visit to The Ohio State University Speech-Language-Hearing Clinic on the day of experimental testing.

Education level. Each participant's education level was obtained by self-report and was scored based on a seven-point scale, taken from the Hollingshead (1975) Index. A one-way analysis of variance (ANOVA) with talker group (i.e., AWS vs. AWNS) as the factor was used to compare scores of education level. There was no statistically significant difference in education level between AWS (M = 5.78, SD = 0.97) and AWNS (M = 6.22, SD = 0.67), $F(1, 16) = 1.28$, $p = .275$.

Table 1. Characteristics of the participants.

	Adults who stutter					Adults who do not stutter		
Participant	Age	Gender	Education	SSI–3 total score	Severity rating from SSI–3	Age	Gender	Education
1	52.0	F	BA	9.0	Very mild	52.0	F	BA
2	51.0	M	BA	29.0	Moderate	52.0	M	C5+
3	35.0	M	BA	11.0	Very mild	38.0	M	C5+
4	34.0	M	C5+	12.0	Very mild	30.0	M	C5+
5	27.0	F	C5+	11.0	Very mild	25.0	M	BA
6	26.0	M	C5+	10.0	Very mild	24.0	M	BA
7	25.0	M	HS	35.0	Severe	24.0	F	BA
8	22.0	M	C3	19.0	Mild	23.0	M	BS
9	19.0	M	C1	38.0	Very severe	23.0	M	C3
M	32.3			19.3		32.3		
SD	12.0			11.6		12.1		

Note. SSI–3 = Stuttering Severity Instrument—Third Edition; F = female; M = male; BA= bachelor of arts; C5+ = graduate degree training; HS = completed high school; C3 = completed 3 years of college; C1 = completed 1 year of college.

Stimuli

A dual-task paradigm was employed in which word pairs and letter strings were presented for rhyme judgments and letter recall, respectively. In the first task, phonological (rhyme) and orthographic manipulations were used, and the participant indicated whether the two words in a pair rhymed. In the second task, two strings of consonant letters were presented prior to and after the pair of words, and the participant indicated whether the strings of letters were the same or different.

Stimuli for rhyme judgments. The stimuli in this study closely matched those used in a study of developmental rhyme judgments by Weber-Fox, Spencer, Cuadrado, and Smith (2003) and in a study of phonological processing in AWS by Weber-Fox et al. (2004). Word pairs were constructed from 60 target words and 240 rhyme-matching words (primes) for a total of 300 different words; these word pairs are presented in the Appendix. Each of the 60 target words was preceded by one of four different rhyme-matching words (60 × 4 = 240). This pairing produced four possible combinations for rhyming and nonrhyming pairs. In particular, there were two sets of rhyming (R+) pairs, consisting of a set of 60 orthographically similar (O+) word pairs (R+O+; e.g., *thrown, own*) and a set of 60 orthographically dissimilar (O–) word pairs (R+O–; e.g., *cone, own*). There were also two sets of nonrhyming (R–) pairs, consisting of a set of 60 orthographically similar (O+) word pairs (R–O+; e.g., *gown, own*) and a set of 60 orthographically dissimilar (O–) word pairs (R–O–; e.g., *cake, own*). Altogether, there were 240 word pairs: 60 pairs for each of the four rhyming/nonrhyming conditions. No rhyme-matching word appeared before more than one target word.

Table 2. Standard scores from subtests of the Test of Adolescent and Adult Language—Third Edition (TOAL–3), by subject.

	Adults who stutter				Adults who do not stutter			
Participant	LV	LG	SV	SG	LV	LG	SV	SG
1	15	12	12	15	16	13	12	11
2	15	7	12	9	12	11	12	11
3	11	12	12	10	16	14	12	17
4	12	12	12	8	16	13	12	17
5	10	12	12	9	9	6	12	10
6	11	11	9	9	13	13	12	13
7	9	7	11	10	9	13	11	14
8	5	11	12	2	5	11	12	10
9	7	8	5	8	13	11	12	11
M	10.6	10.2	10.8	8.9	12.1	11.7	11.9	12.7
SD	3.3	2.2	2.4	3.3	3.8	2.4	0.3	2.8

Note. LV = listening vocabulary; LG = listening grammar; SV = speaking vocabulary; SG = speaking grammar.

The means/medians (and *SD*s) of the word frequencies per million for the primes in the R+O+, R–O+, R+O–, and R–O– sets and for the target words were 137.3/30.0 (274.3), 252.6/42.0 (447.0), 124.3/15.0 (261.3), 167.6/28.0 (327.8), and 132.8/30.0 (236.4), respectively (Francis & Kucera, 1982). For the frequency data of 31 words, a value of 1 was entered when the Francis and Kucera (1982) normative data did not have the word or showed a "no response." Only 14 of the 300 words used (4.7%) had a word frequency higher than 2,000, and these high-frequency words (such as *to*, *are*, *have*) were distributed evenly across rhyme conditions (three in each one), and two high-frequency words were targets. Only 40 words (13.3%) had a frequency higher than 500. No significant differences were found for word frequency across the four sets of rhyme-matching words and the target words as assessed by a one-way ANOVA, $F(4, 281) = 1.57$, $p = .183$.

Stimuli for letter recall. The stimuli for the second task—a memory task (MT)—consisted of easily recognizable and frequently occurring capital letters: B, C, D, F, G, H, J, K, L, M, P, R, S, and T. When no letters were presented prior to the pair of rhyming words, the participant was shown five dashes, "- - - - -" (MT1). The letters for the remaining two conditions were randomly presented in groups of three-letter (MT2) or five-letter (MT3) combinations. Each of these conditions occurred one third of the time in the entire stimulus set of 240 word pairs. Following the response to the rhyming pair, the participant was shown another three- or five-letter string that was either identical to the first letter string or differed by a single letter. When the string of letters differed by a single letter, both the position of that letter in the sequence and the alternate replacement letter were randomly chosen. No individual letter was repeated in any of the three- or five-letter strings.

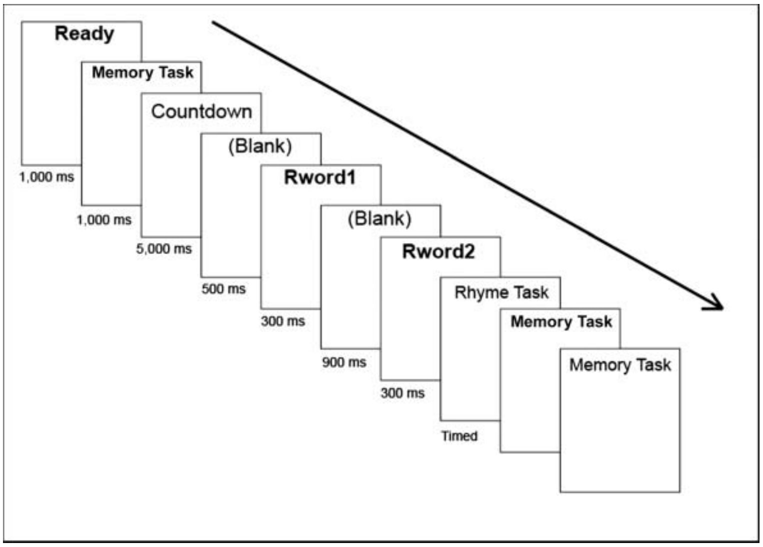
Procedure

The participant was seated in a sound-conditioned booth and was positioned 36 in. from a 17-in. computer monitor. The participants were informed of the importance of making the rhyme judgment "as quickly and accurately as possible." The experiment followed the sequence shown in Figure 1.

A given trial began with a display of the word "Ready" on the screen, and the sequence began 1,000 ms after this display was presented. The "Ready" screen was followed by the MT stimulus (e.g., *CKM*), which remained on the screen for 1,000 ms. The participant then viewed a countdown of numbers from 10 to 1, each flashing on the screen individually for a total countdown time period of 5,000 ms. A blank screen then appeared for 500 ms, after which the first word in the pair (*prime*/Rword1) was presented for 300 ms. Following Rword1, a blank screen appeared for 900 ms, and then the second word (*target*/ Rword2) was presented for 300 ms. As soon as Rword2 was presented, the participant made the rhyme judgment using a "yes" or "no" keystroke. Participants were allowed 3,500 ms for their rhyme decisions. Following the keystroke, a second letter string was shown, consisting of three or five letters that were either identical to the initial MT stimulus (e.g., *CKM*) or dissimilar by one letter (e.g., *BKM*). The participant indicated whether the MT stimuli were the same using a "yes" or "no" keystroke. There was no time constraint for the MT stimulus recall. Response keys alternated "yes" and "no" position between right and left hand evenly across groups.

Prior to the experiment, each participant performed a familiarization task, consisting of 20 trials that included at least one instance of each rhyming pair coupled with one of the concurrent MT conditions. None of the word pairs used in the familiarization task represented pairs found in the actual rhyme judgment task. The experiment then followed. The complete set

Figure 1. Time course of an individual experimental trial, including the rhyming decision and short-term memory tasks that were used to elicit reaction times and judgment accuracy. MT = letter sequence for memory task; Rword1 = first word of rhyme decision task; Rword2 = second word of rhyme decision task.



of 240 word pairs was administered in three blocks of 80 pairs each, and the participant was given a short break between blocks. Each of the three MT conditions was represented within each block. Each participant was randomly assigned to, and completed, one of six pseudorandomized stimulus sets, which were created using a random number generator.

Data Analysis

Accuracy. Rhyme judgment accuracy and letter recall accuracy were determined by the percent correct scores for each type of response. However, as is well known, within proportional scales (such as percentages), the variances are correlated with the means, and the data are not normally distributed (Studebaker, 1985). To overcome this problem, the raw percentage data were arcsine transformed prior to analysis. However, for the benefit of the reader, the means provided in the text and the figures are reported in untransformed percentages. The accuracy for each task was analyzed separately using a mixed-model repeated measures ANOVA; the within-subject factors were rhyme (R+O+, R–O+, R+O–, R–O–) and memory condition (MT1, MT2, MT3), and the between-subject factor was group (AWS, AWNS). In this and subsequent ANOVAs in this study, the degrees of freedom for the F tests were Greenhouse-Geisser adjusted, when necessary, to reduce problems associated with violations of sphericity. For all significant main effects and interactions, a measure of the effect size—partial eta squared (η^2)—is also reported in addition to the significance values. η^2 values should be considered an estimate of the proportion of variance explained by a dependent variable when controlling for other factors. Independent- and dependent-samples t tests were used for subsequent post hoc analyses.

RT. RT (in ms) was measured from the beginning of the onset of the display of the target stimulus to the keystroke response. RTs below 200 ms and above 2,500 ms were eliminated for all participants. This follows Weber-Fox et al. (2004), who eliminated all button presses faster than 200 ms and slower than 1,800 ms, stating that 1,800 ms was the necessary time to make quick and accurate responses to the stimulus of a rhyme judgment task. In the present study, we allowed a maximum RT of 2,500 ms due to the increased cognitive load induced by the dual task with added letter recall component. Mean RT between 200 ms and 2,500 ms were calculated for each participant, and all RTs that were not within 2 *SD*s of the mean were eliminated (see Ratcliff, 1993, for a discussion of methods for dealing with RT outliers). RT calculations were based on correct rhyme judgment responses. Several studies have shown that RT in a speeded classification task produce a more sensitive measure of performance than do errors (e.g., Ben-Artzi & Marks, 1995). RTs were then averaged across each participant for each rhyme and MT condition. The same ANOVA model as that used to analyze the accuracy data was used to assess the RT responses.

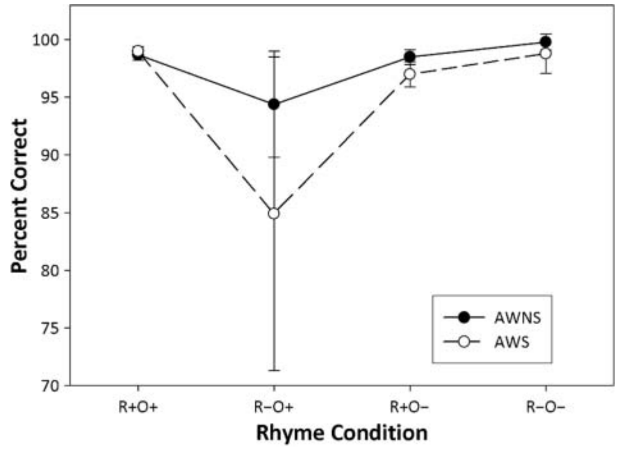
Results

Rhyme Judgments

Accuracy. As expected, the accuracy of rhyme judgments was significantly affected by the type of rhyme and orthographic condition, $F(3, 48) = 12.2$, $p < .001$, $\eta^2 = .432$. For all participants, accuracy was significantly reduced in the most difficult R–O+ condition, and post hoc tests showed that the responses in the remaining three conditions did not differ significantly from one another. Although the accuracy for AWS ($M = 94.9\%$) was lower than that for AWNS ($M = 97.8\%$), this main effect of group did not reach significance, $F(1, 16) = 2.58$, $p = .128$, $\eta^2 = .139$. The Group × Rhyme interaction also did not reach significance, $F(3, 48) = 2.22$, $p = .097$, $\eta^2 = .122$, but it is noteworthy that the drop in accuracy for the R–O+ condition relative to the other three conditions was larger for the AWS than for the AWNS, as illustrated in Figure 2.

Thus far, the present results for rhyme judgment accuracy are consistent with those reported by Weber-Fox et al. (2004), who also did not find statistically significant differences between the performance of AWS and AWNS, although the drop in accuracy in the R–O+ condition was also larger for AWS in their data. The addition of the letter recall component in our study resulted in further

Figure 2. Mean percent rhyme accuracy (± standard error) for adults who stutter (AWS, $n = 9$) and adults who do not stutter (AWNS, $n = 9$) across rhyme conditions (R+O+ = rhyme and orthographically congruent, R–O+ = nonrhyme and orthographically congruent, R+O– = rhyme and orthographically noncongruent, R–O– = nonrhyme and orthographically noncongruent).



findings. In particular, neither the main effect of memory condition, $F(3, 32) = 0.716$, $p = .496$, $\eta^2 = .043$, nor the Group × Memory Condition interaction, $F(3, 32) = 0.39$, $p = .962$, $\eta^2 = .002$, were significant. This shows that both AWS and AWNS performed similarly in each memory condition (i.e., the recall of the three-letter and five-letter strings) and that the increase in the cognitive load did not significantly affect rhyme judgments of either participant group. However, there was a significant Rhyme × Memory Condition interaction, $F(6, 96) = 3.93$, $p = .001$, $\eta^2 = .197$, illustrated in Figure 3. Accordingly, the increase in cognitive load had a significant effect on rhyme accuracy in the R–O+ condition but did not affect the three remaining conditions. In the R–O+ condition, the accuracy was lower when the participants were asked to recall the three-letter string (MT2) and was even lower when the participants were asked to recall the five-letter string (MT3). These results indicate that the increased cognitive load in the present experiment further reduced accuracy in the phonological processing condition that is already the most demanding. However, even when rhyme judgment decisions were most cognitively taxing, accuracy was not significantly different for AWS and AWNS, as shown in a lack of significant interaction between group, rhyme, and memory condition, $F(6, 96) = 0.803$, $p = .568$, $\eta^2 = .048$.

RT. Overall group differences in reaction time were found, showing that RTs for AWS were significantly slower (the delays were 241 ms greater) than those for AWNS, $F(1, 16) = 6.3$, $p = .023$, $\eta^2 = .283$. This result is different from that noted in Weber-Fox et al. (2004), who did not find any group differences in RT for rhyme judgments. The main effect of rhyme was also significant, $F(3, 48) = 49.0$, $p < .001$, $\eta^2 = .754$, and post hoc tests revealed that RT for the R–O+ condition were slower compared with those for the other three conditions. A significant Group × Rhyme interaction was obtained because AWS had significantly slower RT in the R–O+ condition than did AWNS, $F(3, 48) = 3.64$, $p = .019$, $\eta^2 = .185$, which is illustrated in Figure 4. The results for the Group × Rhyme interaction correspond to those reported by Weber-Fox et al. (2004).

Overall, different cognitive loads (MT1, MT2, and MT3) did not affect RT, as indicated by the lack of a significant main effect of memory condition, $F(3, 32) = 1.81$, $p = .179$, $\eta^2 = .102$. However, a significant memory Condition × Rhyme interaction revealed that RT increased for the R–O+ condition when the demands on letter recall were highest (MT3), $F(3.69, 96.00) = 5.81$, $p < .001$, $\eta^2 = .266$, Greenhouse–Geiser. Furthermore, there were significant group differences in RT as a function of memory condition, as indicated by a significant Group × Memory Condition interaction, $F(3, 32) = 3.69$, $p = .036$, $\eta^2 = .188$. As illustrated in Figure 5, this interaction showed that RT for the AWNS did not differ significantly across the three memory conditions, but the RTs for AWS varied and were significantly shorter for MT2 (the three-letter string) relative to either MT1 or MT3. However, even when the letter recall task and rhyme judgment decisions were most cognitively taxing, the RTs were not significantly different for AWS and AWNS, as shown by the lack of significant interaction between group, rhyme, and memory condition, $F(6, 96) = 0.615$, $p = .72$, $\eta^2 = .037$.

Figure 3. Mean percent rhyme accuracy (± standard error) collapsed across all participants ($N = 18$), by rhyme (R+O+ = rhyme and orthographically congruent, R–O+ = nonrhyme and orthographically congruent, R+O– = rhyme and orthographically noncongruent, R–O– = nonrhyme and orthographically noncongruent) and memory (MT1 = no letter recall, MT2 = 3-letter recall, MT3 = 5-letter recall) conditions.

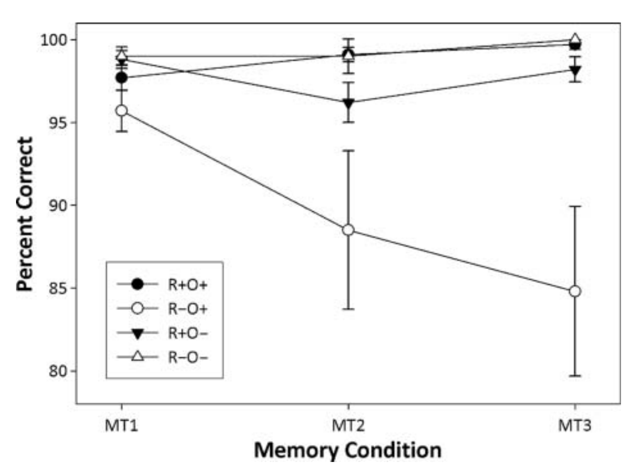


Figure 4. Mean (± standard error) reaction time for AWS ($n = 9$) and AWNS ($n = 9$) across rhyme conditions (R+O+ = rhyme and orthographically congruent, R–O+ = nonrhyme and orthographically congruent, R+O– = rhyme and orthographically noncongruent, R–O– = nonrhyme and orthographically noncongruent).

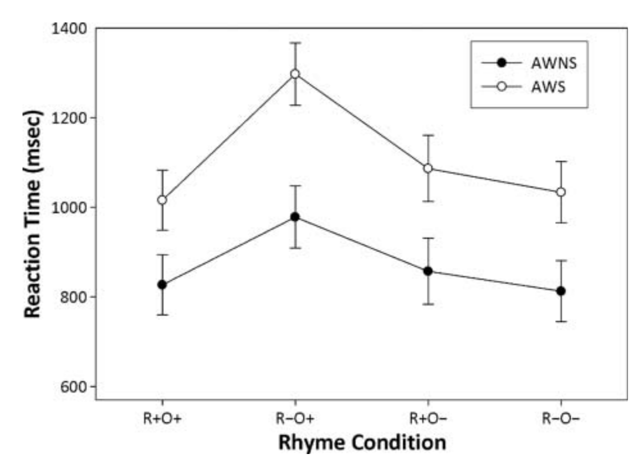
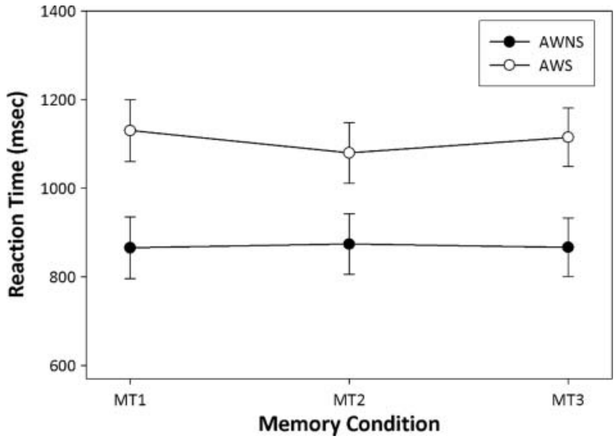


Figure 5. Mean (± standard error) reaction times for AWS (n = 9) and AWNS (n = 9) across memory conditions (MT1 = no letter recall, MT2 = 3-letter recall, MT3 = 5-letter recall).



Letter Recall

Accuracy. The accuracy of letter recall was assessed for the three-letter (MT2) and five-letter (MT3) memory conditions but only for those responses when the rhyme decision was correct. A significant main effect of memory condition indicated that recalling a three-letter string resulted in higher accuracy (M = 94.1%) compared with recalling a five-letter string (M = 88.9%), $F(1, 16) = 36.4$, $p < .001$, $\eta^2 = .695$. A significant Group × Memory Condition interaction, $F(1, 16) = 4.86$, $p = .042$, $\eta^2 = .233$, revealed that the performance of AWS, when compared with that of AWNS, was worse in the MT3 condition (M = 83.0% and M = 90.2%, respectively) than in the MT2 condition (M = 94.8% and M = 95.6%, respectively). This indicates that increased demands on memory in MT3 negatively affected recall of letter combinations of AWS compared with those of AWNS. No other main effects or interactions were significant.

Summary and Discussion

The primary goal of this study was to determine whether phonological processing in AWS differs from AWNS when cognitive load is increased in a concurrent attention-demanding task. Under dual-task conditions, the participants made rhyme judgments while paying additional attention to independent strings of letters, which they recalled after processing the phonological and orthographic information in the rhyming words. In general, AWS were found to be as accurate as AWNS in making their rhyme decisions. This result may seem surprising at first and is not in line with our initial predictions as to the decreased accuracy of rhyme judgments by AWS. However, as expected, the speed of phonological processing differed significantly between the two groups; that is, AWS were slower in their responses than were AWNS. Because the dual-task demands affected RTs but did not differentially affect accuracy of rhyme judgments, there seems to be a speed–accuracy trade-off in that more time was needed by AWS to make a rhyme judgment as accurately as possible. Because of this apparent trade-off, the rhyme judgment accuracy of AWS was not compromised.

These results indicate that the phonological processing system of AWS, compared with that of AWNS, is slower and more vulnerable to delays from concurrent cognitive processes, which is in general agreement with other reports that responses of AWS are slower than those of AWNS for various speech or nonspeech tasks (see Table 5-3 of Bloodstein & Bernstein-Ratner, 2008). However, the hypothesis that the AWS system is more error prone (e.g., Postma & Kolk, 1993, 1997) is not supported at present. Considering that other studies have not found significant differences in RTs of AWS and AWNS during rhyme decision tasks across all conditions (e.g., Arnstein, Lakey, Compton, & Kleinow, 2011; Weber-Fox et al., 2004), the present results emphasize the detrimental influence of concurrent dual-task conditions on phonological processing in AWS. In particular, it is possible that the working memory task may have drawn on resources that directly overlap with those involved in the rhyme decision task (see Baddeley, 2003, for a review of working memory involvement in phonological processing).

Assuming the possibility of a speed–accuracy trade-off during dual-task conditions, the current results support the notion that increases in cognitive processing load affect speech-language processes differentially in AWS and AWNS (Bosshardt, 2006). Furthermore, given that AWS reported a history of stuttering treatment, it is possible that the speed–accuracy trade-off displayed by AWS may represent a learned preference toward extended processing times and more accurate responses. This possibility seems plausible because some therapeutic approaches promote “slower speech” (for further review of treatment approaches, see Chapter 14 of Bloodstein & Bernstein-Ratner, 2008), which may extend the processing times of AWS. Thus, the extended processing time of at least some AWS may reflect a “learned strategy of stutterers to slow down to reduce the risk of fluency failure” (Bakker & Brutten, 1989, p. 243).

Another significant group difference was found in RTs when task demands were highest—that is, when the encoding of different phonological information was challenged by similarity of orthographic representation, such as in *bomb, tomb*. In this particular rhyme condition, the responses of AWS were also slower compared with those of AWNS. Although Weber-Fox et al. (2004) also reported significantly slower responses of AWS in this condition, the delays in our study were much greater (319 ms) compared with those in their study (about 100 ms). This suggests that the dual-task demands additionally affected the speed of phonological processing of AWS when rhyme decisions were already cognitively taxing. Given that the responses of the current AWS participants were also slower, compared with those of AWNS, in this most demanding rhyme condition, we may conclude that the speech-language processing systems of AWS are more susceptible to interference from co-occurring processing demands (e.g., Bosshardt, 2002, 2006; Bosshardt et al., 2002; Caruso et al., 1994; Kleinow & Smith, 2000).

Kramer and Donchin (1987) suggested that one possible (but not only) source of the response delays in the rhyme matching task—even with AWNS—could be a tendency to withhold a response when an orthographic/phonological code conflict was discovered. This tendency thus may be exacerbated in AWS. If increased delays come when there is an information conflict between the orthographic code and phonological code activated in the word recognition process, at what point in the process does this occur? Kramer and Donchin (1987) used a task similar to that used here (but without the memory task) measuring ERPs (N200 and P300 latencies) as well as RTs and percent errors. They found a similar increase in RTs to the (R–O+) pairs. Looking at the pattern of P300 latencies and RTs, they suggested that the interaction (and, thus, the interference) of the orthographic and phonological codes began during the stimulus evaluation stage, but the effect of the interaction was magnified during the later stages of processing—the latter perhaps a result of a cascading effect in mental processing (McClelland, 1979). However, although Weber-Fox et al. (2004) also found an increase in P300 latencies in the R–O+ condition, they reported that these early neural processes operated similarly for AWS and AWNS. It is tempting, then, to speculate that at least some of the increased RTs in AWS stems from increased interference in the later stages of word recognition (and, perhaps, that they are more likely to process irrelevant information). However, our data cannot speak directly to that question.

The speed of phonological processing of AWS compared with that of AWNS also varied as a function of complexity of the letter string that the participants were to recall. Greater delays were found (a) when rhyme judgments were made concurrently while preserving in memory a more complex five-letter combination compared with a three-letter combination and (b) when no letters (i.e., five dashes) were shown prior to the rhyming pair. Although the slower responses in conjunction with the longer letter string can be expected, obtaining the slower responses with no letters is surprising. One explanation may be that the cognitive load associated with the three-letter recall task did not tax the AWS sufficiently to slow responding; rather, it may have enhanced sustained attention to the task and improved the performance of AWS, whereas they tended to "drift off" more when there were no letters (MT1) to recall. This interpretation is consistent with findings that AWS require greater sustained attention to perform linguistic and cognitive tasks in dual-task paradigms (for a summary, see Bosshardt, 2006) and display impaired skills to focus attention (Heitmann, Asbjørnsen, & Helland, 2004). It is also consistent, albeit to a lesser degree, with findings that children who do and do not stutter differ on measures of attention (e.g., Eggers, De Nil, & Vanden Bergh, 2010; Felsenfeld, van Beijsterveldt, & Boomsma, 2010; Karrass et al., 2006).

It was also of interest to the study whether memory recall of AWS for stimuli presented concurrently with the rhyming words is more susceptible to increased cognitive loads. We expected an overall decrease in accuracy for the recall of letter strings regardless of their complexity. Instead, it was found that responses of AWS were less accurate compared with those of AWNS only for the more complex five-letter combination when considering only those cases in which rhyme judgments for both groups were correct. This indicates that the accurate cognitive processing of AWS, when compared with that of AWNS, is more vulnerable to errors as task difficulty increases, especially during a dual-task paradigm. As Bosshardt (2006) suggested, if the speech-language and other central executive systems are less "modularized" (i.e., concurrent tasks draw on the same neurocognitive resources) for AWS than for AWNS, then concurrent tasks would be more likely to have detrimental effects on the performance of AWS during dual-task situations (for a review, see Bajaj, 2007). Notably, a mounting body of evidence indicates that concurrent tasks involving the central executive affect the performance of AWS to a greater degree than those of AWNS on a variety of speech (e.g., Bosshardt, 1999, 2002; Bosshardt et al., 2002; Caruso et al., 1994; De Nil & Bosshardt, 2000; cf. Arends, Povel, & Kolk, 1988; Vasic & Wijnen, 2005) and nonspeech (e.g., Brutten & Trotter, 1986; Greiner, Fitzgerald, & Cooke, 1986; Smits-Bandstra, De Nil, & Rochon, 2006; Sussman, 1982) tasks. If true, this may explain why accuracy on the recall of five-letter combinations degraded at a greater rate for AWS than for AWNS as the difficulty within the dual-task paradigm increased.

Conclusion

The present study explored differences between AWS and AWNS in phonological processing using a rhyme decision task, while concurrently varying degrees of cognitive load. The results showed that AWS, compared with AWNS, displayed poorer performance on RT and selected accuracy measures during phonological and cognitive processing tasks, especially as the cognitive load increased.

These findings support the notion that the speech-language and cognitive processing systems of AWS are more vulnerable to disruptions from concurrent attention-demanding stimuli. These vulnerabilities may contribute to the difficulties that AWS have in terms of initiating and/or maintaining fluent speech-language planning and production. Mechanisms that may account for the discrepancies between the groups may include, but are not limited to, differences in (a) attentional processes (especially during dual-task situations), (b) modularization of speech-language and cognitive processes (i.e., less modularized allows for greater interference from dual tasks), and/or (c) another unspecified difference in phonological and cognitive processing during dual-task conditions. Further research is needed to better understand the processes that may account for these differences.

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Appendix (p. 1 of 2). Word pairs.

R+O+		R–O+		R+O–		R–O–	
SWEAR	PEAR	CLEAR	PEAR	AIR	PEAR	GREAT	PEAR
TONE	PHONE	ONE	PHONE	LOAN	PHONE	THOUGH	PHONE
GLOW	BLOW	BROW	BLOW	DOE	BLOW	STOLE	BLOW
NO	GO	DO	GO	SHOW	GO	STOOD	GO
ONE	DONE	STONE	DONE	SUN	DONE	GLOW	DONE
TO	WHO	SO	WHO	BLUE	WHO	ARE	WHO
WEIGHT	EIGHT	HEIGHT	EIGHT	LATE	EIGHT	SLOW	EIGHT
WHERE	THERE	HERE	THERE	HAIR	THERE	ON	THERE
OUR	HOUR	POUR	HOUR	FLOWER	HOUR	EVEN	HOUR
THOUGH	DOUGH	COUGH	DOUGH	MOW	DOUGH	WOOL	DOUGH
STEW	GREW	SEW	GREW	THRU	GREW	FOWL	GREW
STOOD	GOOD	MOOD	GOOD	WOULD	GOOD	BROWN	GOOD
SIGHT	MIGHT	FREIGHT	MIGHT	WRITE	MIGHT	BED	MIGHT
TREAT	EAT	GREAT	EAT	MEET	EAT	LEARN	EAT
PRONE	SCONE	NONE	SCONE	GROAN	SCONE	BLAST	SCONE
STEAK	BREAK	WEAK	BREAK	CAKE	BREAK	STUFF	BREAK
FAR	CAR	WAR	CAR	ARE	CAR	PAID	CAR
SOUR	SCOUR	FOUR	SCOUR	POWER	SCOUR	PUT	SCOUR
TOLL	POLL	DOLL	POLL	STOLE	POLL	WASTE	POLL
TIER	PIER	DRIER	PIER	SMEAR	PIER	CROW	PIER
TEA	SEA	IDEA	SEA	FREE	SEA	BOARD	SEA
BROOD	FOOD	FLOOD	FOOD	CRUDE	FOOD	THROWN	FOOD
FORM	STORM	WORM	STORM	WARM	STORM	COME	STORM
DREAD	BREAD	BEAD	BREAD	SHED	BREAD	NOUN	BREAD
WOOD	HOOD	BLOOD	HOOD	COULD	HOOD	AIR	HOOD
FEAR	EAR	BEAR	EAR	DEER	EAR	STONE	EAR
BAT	CAT	OAT	CAT	MATTE	CAT	CHOIRS	CAT
PAID	MAID	SAID	MAID	GRADE	MAID	DO	MAID
LEARN	EARN	BARN	EARN	TURN	EARN	LATE	EARN
YEAST	BEAST	BLAST	BEAST	PRIEST	BEAST	CLONE	BEAST
GROW	SNOW	COW	SNOW	HOE	SNOW	FREIGHT	SNOW
CRATER	LATER	WATER	LATER	WAITER	LATER	OAT	LATER
THROWN	OWN	GOWN	OWN	CONE	OWN	CAKE	OWN
ELEVEN	SEVEN	EVEN	SEVEN	HEAVEN	SEVEN	SUN	SEVEN
SOOT	FOOT	LOOT	FOOT	PUT	FOOT	STEW	FOOT
CREASE	LEASE	EASE	LEASE	NIECE	LEASE	WORM	LEASE
SON	TON	ON	TON	GUN	TON	HAIR	TON
BULL	FULL	DULL	FULL	WOOL	FULL	CRUDE	FULL
FOWL	HOWL	BOWL	HOWL	TOWEL	HOWL	NONE	HOWL
PLIERS	FLIERS	SKIERS	FLIERS	CHOIRS	FLIERS	BEAD	FLIERS
WASTE	HASTE	CASTE	HASTE	WAIST	HASTE	DEER	HASTE
KNOWN	BLOWN	BROWN	BLOWN	BONE	BLOWN	TO	BLOWN

Appendix (p. 2 of 2). Word pairs.

R+O+		R–O+		R+O–		R–O–	
TOWN	CROWN	SHOWN	CROWN	NOUN	CROWN	POUR	CROWN
DEAD	HEAD	KNEAD	HEAD	BED	HEAD	COULD	HEAD
LORD	FORD	WORD	FORD	BOARD	FORD	SOUR	FORD
HOME	DOME	COME	DOME	FOAM	DOME	IDEA	DOME
VOW	PLOW	CROW	PLOW	BOUGH	PLOW	DRIER	PLOW
FLOWN	SOWN	DOWN	SOWN	CLONE	SOWN	CORK	SOWN
SLAVE	CAVE	HAVE	CAVE	WAIVE	CAVE	ROOM	CAVE
TRUTH	YOUTH	SOUTH	YOUTH	BOOTH	YOUTH	RAID	YOUTH
RAID	BRAID	PLAID	BRAID	JADE	BRAID	WOE	BRAID
WOMB	TOMB	BOMB	TOMB	ROOM	TOMB	LOWER	TOMB
DOVE	LOVE	MOVE	LOVE	OF	LOVE	TOES	LOVE
PROSE	NOSE	LOSE	NOSE	TOES	NOSE	SPRUCE	NOSE
BALL	HALL	SHALL	HALL	CRAWL	HALL	SLAVE	HALL
SUCH	TOUCH	COUCH	TOUCH	HUTCH	TOUCH	TOAST	TOUCH
HOST	MOST	COST	MOST	TOAST	MOST	COUCH	MOST
SHOWER	TOWER	LOWER	TOWER	FLOUR	TOWER	BOOTH	TOWER
CORK	PORK	WORK	PORK	TORQUE	PORK	SHALL	PORK
LOOSE	GOOSE	CHOOSE	GOOSE	SPRUCE	GOOSE	CREASE	GOOSE

Note. R+ = rhyme; R– = nonrhyme; O+ = orthographically similar; O– = orthographically dissimilar.