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Research Article

Dyslexia Limits the Ability to Categorize Talker Dialect

Gayle Beam Long,[a] Robert Allen Fox,[a] and Ewa Jacewicz[a]

Purpose: The purpose of this study was to determine whether the underlying phonological impairment in dyslexia is associated with a deficit in categorizing regional dialects.
Method: Twenty adults with dyslexia, 20 school-age children with dyslexia, and 40 corresponding control listeners with average reading ability listened to sentences produced by multiple talkers (both sexes) representing two dialects: Midland dialect in Ohio (same as listeners' dialect) and Southern dialect in Western North Carolina. Participants' responses were analyzed using signal detection theory.
Results: Listeners with dyslexia were less sensitive to talker dialect than listeners with average reading ability. Children were less sensitive to dialect than adults. Under stimulus uncertainty, listeners with average reading ability were biased toward Ohio dialect, whereas listeners with dyslexia were unbiased in their responses. Talker sex interacted with sensitivity and bias differently for listeners with dyslexia than for listeners with average reading ability. The correlations between dialect sensitivity and phonological memory scores were strongest for adults with dyslexia.
Conclusions: The results imply that the phonological deficit in dyslexia arises from impaired access to intact phonological representations rather than from poorly specified representations. It can be presumed that the impeded access to implicit long-term memory representations for indexical (dialect) information is due to less efficient operations in working memory, including deficiencies in utilizing talker normalization processes.

Dyslexia is a lifelong complex neurobiological condition that is characterized by difficulty with accurate and fluent word recognition and by poor spelling and decoding abilities (National Institute of Child Health and Human Development, 2002). A convergence of evidence from the fields of neuroscience, psychology, education, linguistics, and speech and hearing science points to a deficit in the underlying phonological component of language as a primary source of these reading and spelling difficulties (Fletcher, Lyon, Fuchs, & Barnes, 2007; Goswami, 2010; Kamhi & Catts, 2012; Pennington, 2009; Rayner, Pollatsek, Ashby, & Clifton, 2011; Robertson, Joanisse, Desroches, & Ng, 2009; Shankweiler & Liberman, 1989; Shaywitz & Shaywitz, 2005). This phonological deficit, in which accessing lexical phonological representations of words appears to be compromised, commonly has been found in individuals with dyslexia (Fraser, Goswami, & Conti-Ramsden, 2010; Ramus & Szenkovits, 2008). In particular, individuals with dyslexia have persistent difficulties processing and manipulating phonological units, such as segmenting and blending phonemes in words, rhyming, and discriminating between speech sounds (Hulme & Snowling, 2009; Uhry, 2005). These difficulties, in turn, decrease their abilities to construct the robust phoneme-to-grapheme mapping required to develop accurate and fluent reading and spelling abilities (Lyon, Shaywitz, & Shaywitz, 2003). It is important to note that the written language disorder of individuals with dyslexia appears to be part of a central phonological impairment rather than the result of a deficit in the cognitive components dedicated to decoding and encoding written language (Ferrer, Shaywitz, Holahan, Marchione, & Shaywitz, 2010; Tunmer & Greaney, 2010; Voller, 2004).

Phonological Processing in Dyslexia

Performance on clinical measures of general phonological ability is strongly predictive of both reading and spelling abilities (Catts & Adolph, 2011; Torgesen, 2007). Research exploring the phonological deficit in dyslexia has revealed three correlated yet distinct aspects of phonological ability impairment that are most relevant to the phonological processing of spoken language and the development of written language skills: phonological awareness, lexical retrieval, and phonological memory.

Phonological awareness refers to an individual's awareness of and access to the phonological structure of

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their language, including their ability to manipulate sublexical units such as syllables and phonemes (Goswami, 2010; Mattingly, 1972; Miller, Sanchez, & Hynd, 2003). There is an abundance of evidence that individuals with dyslexia have poor phonological awareness (Catts, Adolph, Hogan, & Ellis-Weismer, 2005; Robertson et al., 2009; Uhry, 2005), although there is ongoing debate whether these difficulties stem from poorly specified phonological representations (Velluntino & Fletcher, 2007) or impaired access to intact phonological representations (Boets et al., 2013).

Lexical retrieval is the ability to quickly retrieve the phonological forms of words from long-term memory. The speed and accuracy of processing the combined visual and phonological forms of words typically is tested in rapid symbolic naming tasks (Lervag & Hulme, 2009; Manis, Doi, & Badha, 2000; Neuhaus & Swank, 2002; Wolf, Bowers, & Biddle, 2000). Again, individuals with dyslexia perform more poorly on these tasks relative to individuals with average reading ability, showing comparatively slower automatized naming, which may indicate slower lexical retrieval (Manis, Seidenberg, & Doi, 1999; Parilla, Kirby, & McQuarrie, 2004; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007; Savage, Pillay, & Melidona, 2007).

Last, phonological memory involves perceiving, phonetically analyzing, and encoding speech sounds for temporary storage in working or short-term memory (Baddeley, 2003; Gathercole & Baddeley, 1990; Savage, Lavers, & Pillay, 2007). Any one of these processes, which are believed to occur within a specific component of working memory called the *phonological loop* (Baddeley, 1986, 2007), might be the source of the phonological memory deficit found in individuals with dyslexia (Brady, 1986). The deficit might arise from problems with perception or problems in the initial phonetic encoding of correctly perceived information. As an alternative, the deficit might stem from a limitation in rehearsing and retrieving information in a phonetic code. Ramus and Szenkovits (2008) more recently proposed that the phonological processing deficit in dyslexia emerges as a function of increased task demands when working memory is involved and does not arise from the underlying phonological representations, which are intact. In particular, the deficit is manifested in tasks that load heavily on working memory and require metalinguistic awareness or rapid processing. This implies that aspects of phonological processing including phonetic encoding, rehearsal, and retrieval involve more resource allocation in individuals with dyslexia. An increase in processing effort may interfere with storing information in working memory within the central-storage capacity limits (Cowan, 2005, 2010) or, relatedly, in the episodic buffer component of Baddeley's (2000) working memory model. Less efficient processing is a plausible source of the phonological memory deficit in dyslexia, which, in turn, inhibits the mapping of speech sounds to print in the decoding (reading) and encoding (spelling) of written words (Hulme & Snowling, 2009; Pennington & Bishop, 2009).

In this article, we adopt the view that the phonological deficit in dyslexia arises from impaired access to intact phonological representations rather than from poorly specified representations (Boets et al., 2013; Dickie, Ota, & Clark, 2013; Hazan, Messaoud-Galusi, & Rosen, 2013; Ramus & Szenkovits, 2008). The difficulties with accessing phonological representations may arise, in part, from deficiencies in working memory processes that impede phonetic coding and constrain the access to information stored in long-term memory. The aim of the current article is to ascertain whether the presence of extensive indexical variation in speech is more detrimental to performance of individuals with dyslexia relative to participants with average reading ability. *Indexical information* pertains to those aspects of variability in speech that are copresent with the linguistic information and that cue both biological and social attributes about a talker, such as age, sex, regional dialect or foreign accent, emotional state, or socioeconomic background. More recent models of the mental lexicon have included these indexical (or episodic) features in the underlying representations, which contain feature slots for both linguistic and indexical information (Goldinger, 1996, 1998; Johnson, 2005, 2006; Pierrehumbert, 2001). The indexical variation is considered an integral part of lexical representations (Nygaard & Pisoni, 1998). It has also been proposed that the perception of spoken words is socially weighted and that listeners encode the same speech signal simultaneously to both linguistic representations and social (indexical) representations (Sumner, Kim, King, & McGowan, 2014). However, it may be the case that the spoken word recognition system treats the linguistic and indexical variability differently. In particular, linguistic phonological variation may be represented more abstractly in memory, and indexical variation may exert its influence later in the course of perception, being represented in a more specific format (Luce, McLennan, & Charles-Luce, 2003).

Our goal in this article is to determine whether dyslexia limits, in some way, access to those indexical representations that cue regional dialects. The findings of the current study will contribute to a better understanding of (a) the sources of phonological ability impairment in dyslexia and (b) the nature of phonological memory deficit, which may also include deficient encoding of indexical cues in speech.

Phonological Memory and Talker Normalization Processes in Dyslexia

Talker and linguistic information inevitably overlap in spoken language. Research suggests that phonological representations are affected by detailed talker-specific information (Creel & Bregman, 2011) and that talker variability decreases the efficiency of speech processing. For example, typical listeners are found to be slower and less accurate in identifying speech sounds when listening to several talkers in a speech perception task as opposed to a single talker (K. P. Green, Tomiak, & Kuhl, 1997; Mullennix & Pisoni, 1990; Nusbaum & Morin, 1992). Memory for word lists is also negatively affected by extensive talker variability; listeners recall fewer words from multiple-talker lists than from single-talker lists (Martin, Mullennix, Pisoni, & Summers, 1989). When the talker changes unpredictably, listeners usually experience increased difficulty encoding words in memory because rapid perceptual adjustment is required to reduce talker interference. This perceptual adjustment, operationally termed *talker normalization* (for a review and discussion of normalization processes, see Pisoni, 1997), is crucial in building associations between the nuances of an individual talker's speech and the listener's phonological representations of speech sounds encoded in long-term memory.

It has been shown that listeners with dyslexia appear to be impaired in their abilities to both recognize voices of multiple talkers (Perrachione, Del Tufo, & Gabrieli, 2011) and utilize talker normalization processes when listening to utterances in their native English language (Perrachione, Del Tufo, Ghosh, & Gabrieli, 2011). In particular, listeners with dyslexia were deficient in recognizing different voices of unfamiliar talkers in English, which was in contrast to control participants, whose accuracy was significantly greater. However, when both listener groups were trained on recognizing different voices in an unfamiliar language (Mandarin), listeners with average reading ability were equally as poor as listeners with dyslexia in their talker identification abilities (Perrachione, Del Tufo, & Gabrieli, 2011). These results indicated that when both listener groups had access to stored phonological representations in their native language, the discrepancies between the listeners with dyslexia and listeners with average reading ability were due to their differential abilities in utilizing talker normalization processes. That is, adults with average reading ability were able to perceptually adjust to individual talker characteristics and retain the nuances of the talkers' voices in working memory in order to associate these peculiarities with stored phonological representations of speech sounds. Listeners with dyslexia, being unable to detect consistent deviations between the talker-specific phonetic variation and their stored abstract representations, were limited in this ability. The differences between the listeners with dyslexia and listeners with average reading ability were eliminated when neither group had access to stored phonological representations in Mandarin and thus were unable to utilize the correspondence between the phonetic variation in talker voices and the underlying phonological representation.

In a second study, Perrachione, Del Tufo, Ghosh, et al. (2011) utilized functional magnetic resonance imaging data to demonstrate that, in listeners with dyslexia, brain regions typically engaged in talker normalization (the superior temporal gyrus, including the primary auditory cortex and Wernicke's area) displayed reduced neurophysiologic adaptation to a single talker during a speech perception task. Speech of a single talker is produced with the same idiosyncratic and consistent features, as opposed to the more variable speech characteristics of multiple talkers. The relative constancy of phonetic variability in the productions of a single talker results in strong adaptive neural processes related to talker normalization. Indeed, controls with average reading ability displayed extensive adaptation to the same single talker (in a one-talker condition) as opposed to four different talkers (in a multiple-talker condition), indicating strong talker normalization effects. However, participants with dyslexia exhibited limited adaptation and were unable to utilize the consistent and predictable indexical features and low phonetic variability in a single talker to establish the phonetic–phonemic correspondences during a speech perception task. Taken together, these results indicate that phonological processing in listeners with dyslexia is less efficient and more physiologically expensive relative to controls with average reading ability who share a common native language. The inability to fully utilize talker normalization in speech processing seems to impair access to abstract phonological representations in dyslexia, interfering with the development of sound-to-letter mapping in reading.

Current Study

The current study examined a specific type of perceptual talker normalization that relies on implicit long-term memory associated with previous exposure to and experiences with phonetic variation in spoken dialects (Pisoni, 1993). Recent research has shown that regional accents cause disruptions in the auditory processing of speech (Floccia, Goslin, Girard, & Konopczynski, 2006) and that typical adult listeners are sensitive to the dynamic dialectal features of a talker's speech (e.g., Clopper, Levi, & Pisoni, 2006). Moreover, lifetime experience with a given dialect through prolonged exposure to the regionally accented variant leads to a native-dialect advantage in phonological processing. The own-dialect advantage becomes apparent when listeners are presented with only brief intervals of speech, such as monosyllabic words (Fox & Jacewicz, 2011; Jacewicz & Fox, 2012). Once an individual's perceptual system becomes attuned to the systematic phonetic variation within a dialect, efficient talker normalization involves integration of both talker idiosyncrasies and the dynamic features of the spoken dialect.

We hypothesized that, compared with controls with average reading ability, adults with dyslexia would be less sensitive to dialect features in the speech of multiple talkers. If the native-dialect advantage is the result of asymmetric cultural experiences with the speech of different talker populations (Perrachione, Chiao, & Wong, 2010), listeners with dyslexia are expected to have developed implicit long-term memory for features of their own dialect. However, the retrieval of these features when listening to voices of unfamiliar talkers is expected to be less effective relative to controls with average reading ability due to both the less efficient processing under increased cognitive load (Ramus & Szenkovits, 2008) and the deficient talker normalization processes in dyslexia (Perrachione, Del Tufo, Ghosh, et al., 2011). That is, the idiosyncratic characteristics of unfamiliar talkers will interfere with dialectal features, and the processing of multiple sources of talker variability may further impede access to stored indexical representations

(Nygaard & Pisoni, 1998; Sumner et al., 2014). As a consequence, the increased processing effort in listeners with dyslexia relative to controls with average reading ability will result in their comparatively lower ability to categorize talker dialect.

The second goal of the current study was to determine the extent to which school-age children with dyslexia, relative to children with average reading ability, have developed sensitivity to dialect features when presented with extensive between-talkers variability. There is some evidence that children with dyslexia score lower than children with average reading ability in consonant discrimination tasks involving multiple talkers (Hazan, Messaoud-Galusi, Rosen, Nouwens, & Shakespeare, 2009). However, research on children's perception of talker variability in relation to regional dialects is scant. It is known that 9- to 12-year-old children with average reading ability perform more poorly than adults when presented with indexical variation in voices of multiple talkers (Jacewicz & Fox, 2014). Their ability to cope with talker variability seems to be still maturing at this age. In particular, their perceptual decisions are comparatively less consistent, most likely due to their less efficient encoding of acoustic–phonetic information in the speech of multiple talkers and relative inexperience with regional variation in speech. However, despite their lower performance scores, children with average reading ability in the Jacewicz and Fox (2014) study identified vowels in their native dialects more accurately than vowels in the nonnative dialects, manifesting native-dialect advantage. In the current study, children with dyslexia were expected to perform more poorly than children with average reading ability, and both child groups were predicted to underperform compared with the adults due to their maturing abilities to cope with between-talkers variability and relative inexperience with regional variation in speech.

Method

Participants

There were 80 participants in the study. The two groups with dyslexia consisted of 20 adults with dyslexia ranging in age from 18 to 72 years (M = 36.7, SD = 17.8) and 20 children with dyslexia ranging in age from 10 to 13 years (M = 12.4, SD = 1.1). The two corresponding control groups consisted of 20 adults with average reading ability ranging in age from 18 to 65 years (M = 39.7, SD = 12.5) and 20 children with average reading ability ranging in age from 10 to 13 years (M =12.7, SD = 0.8). An independent-samples t test revealed no significant differences in chronological age between the two adult groups, $t(38) = 0.6$, $p = .530$, or between the two child groups, $t(38) = 0.8$, $p = .470$. There were 10 male and 10 female participants in each group. All of the children attended school and ranged from fifth grade to eighth grade. All participants were lifelong residents of central Ohio and native speakers of the dialect of American English spoken in that region. They were paid volunteers naïve to the purpose and methods of the study. The study protocol, including the consent, assent, and parental consent forms, was approved by the institutional review board at The Ohio State University.

The children with dyslexia (a) had received a formal diagnosis of dyslexia from a qualified professional, (b) demonstrated a history of difficulty decoding (reading) and encoding (spelling) written language, and (c) were currently being served under an individualized education plan with reading and spelling goals or utilized a Section 504 plan under the Americans with Disabilities Act with accommodations for reading and spelling. Adults with dyslexia reported (a) a childhood history of difficulty learning to read, (b) current difficulty or anxiety regarding reading aloud, (c) poor spelling ability, (d) slower silent reading with good comprehension skills, and (e) receiving a scaled score of 7 (*below average*) or less on at least one subtest of the Comprehensive Test of Phonological Processing–Second Edition (CTOPP-2; Wagner, Torgesen, Raschotte, & Pearson, 2013). The children and adults with average reading ability had no history of difficulty learning to read or spell and no current difficulties reading material appropriate for their age and education level. Regarding cognitive function, the children in both groups had scored within the average to above-average range on Cognitive Abilities Test–Form 6 (Lohman & Hagan, 2005), which was administered at school. All adults were, at minimum, high school graduates. All participants passed a bilateral pure-tone hearing screening and had pure-tone thresholds of $\leq$ 20 dB HL at octave frequencies from 250 through 8000 Hz (American National Standards Institute, 2004).

The CTOPP-2 was administered for all participants prior to their participation in the study. The CTOPP-2 scores, displayed in Table 1, are of interest because the test measures three phonological processing abilities that are related to reading ability: phonological awareness, rapid symbolic naming, and phonological memory (Wagner et al., 1997). Participants with dyslexia obtained significantly lower scores on all components of the CTOPP-2 than did participants with average reading ability as determined by independent-samples t tests ($p < .001$ for each component).

Stimulus Materials

Meaningful short sentences selected from spontaneous conversations of 40 talkers (20 from Ohio and 20 from North Carolina) were the stimuli in the perception test. There were 10 male talkers and 10 female talkers in each group. The Ohio talkers were born and raised in Central Ohio and spoke the Midland variety of American English, which was also the dialect of the listeners in the current study. The North Carolina talkers came from Western North Carolina and spoke a variety of Southern American English known for its strong Southern features (Labov, Ash, & Boberg, 2006). These talkers were a subset of the talkers included in a larger recorded corpus of regional variation (e.g., Jacewicz, Fox, & Salmons, 2011; Jacewicz, Fox, & Wei, 2010). The talkers ranged in age from 52 to

Table 1. Mean (*SD*) scores for assessment measures of phonological ability on the Comprehensive Test of Phonological Processing–Second Edition (CTOPP-2) for participants with dyslexia and participants with average reading ability (AR).

	Adults		Children	
CTOPP-2 composite	**Dyslexia**	**AR**	**Dyslexia**	**AR**
Phonological awareness	84 (13)	119 (17)	84 (12)	119 (11)
Elision	8 (2)	11 (2)	8 (1)	12 (2)
Blending	8 (2)	12 (2)	9 (2)	12 (2)
Phoneme isolation	5 (2)	15 (4)	5 (2)	14 (3)
Phonological memory	79 (17)	113 (13)	83 (15)	116 (12)
Memory for digits	6 (3)	13 (3)	7 (3)	13 (3)
Nonword repetition	7 (3)	11 (2)	7 (2)	12 (2)
Rapid symbolic naming	81 (15)	109 (11)	85 (15)	109 (11)
Rapid digit naming	7 (3)	11 (2)	7 (3)	11 (2)
Rapid letter naming	7 (3)	11 (2)	7 (2)	11 (2)

Note. Composite scores are reported as standard scores. Subtest scores are reported as scaled scores.

68 years. The mean ages of the talkers from Ohio were 57.7 years (*SD* = 3.4) for men and 60.8 years (*SD* = 5.9) for women, and the mean ages of the talkers from North Carolina were 58.8 years (*SD* = 5.9) for men and 59.4 years (*SD* = 2.8) for women. Each talker produced two sentences for a total of 80 sentences from all 40 talkers. A complete set of sentences used in the study is included in the Appendix. The sentences did not contain semantic cues suggestive of the geographic region or background of the talkers. The complete stimulus set was auditorily checked by the experimenters to ensure that there were no dysfluencies present and that the speech was appropriate for each dialect. All sound files were equated for root-mean-square amplitude.

Procedure

The experimental task was a forced-choice identification task. The randomized speech samples were delivered diotically over Sennheiser (Wedemark, Germany) HD 600 headphones in one block at a comfortable listening level. Upon hearing each sentence, the listener responded by clicking with the mouse on one of two boxes on the computer screen that displayed the two responses: *Ohio* and *North Carolina*. The participants were instructed that they would hear one sentence at a time and had to decide whether the sentence was produced by an Ohio talker or a North Carolina talker. No repetitions were allowed, and the listeners were asked to guess if they were uncertain about which response to choose. Each listener was tested individually, and the experiment was self-paced. The stimulus presentation and response collection were under the control of a custom MATLAB program. For familiarization with the task, an eight-token practice run was administered to each listener prior to the experiment. Both the sentences and talkers in the practice were different from those in the experiment. No feedback about the accuracy of the listener's responses was provided on either the practice block or the actual experiment.

Results

Overall, all listeners were able to categorize talker dialect relatively well (M = 78.6% correct), although both groups with dyslexia scored lower (M = 73.7%) than the corresponding groups with average reading ability (M = 83.5%), and adults (M = 82.3%) performed better than children (M = 74.9%). However, as is well known, percentage correct scores do not represent performance well because sensitivity to stimulus differences is not separable from the response bias used in making identification judgments. In addition, percentage correct scores cannot easily account for a listener's decisions made under different degrees of stimulus uncertainty (Lynn & Barrett, 2014). To better understand the above categorization decisions, participants' responses were analyzed using signal detection theory, which allows for separating listeners' sensitivity to dialect from their response bias (D. M. Green, & Swets, 1966; Macmillan & Creelman, 2005). The responses were initially measured in terms of hits and false alarms. The correct categorization of an Ohio talker was a hit, and the categorization of a North Carolina talker as an Ohio talker was a false alarm. This choice was made because Ohio was the most common dialect heard by the listeners who grew up in Central Ohio. (Note that the correct categorization of the North Carolina talker as a hit, and selection of an Ohio talker as a North Carolina talker to be a false alarm, would produce equivalent results.) Each participant's categorization performance was then transformed into A' values, a nonparametric analogue of d' sensitivity measure in signal detection theory (Grier, 1971; Snodgrass & Corwin, 1988; Stanislaw & Todorov, 1999). A' is a distribution-free measure and is less dependent than d' on assumptions regarding normal distribution of scores. We calculated A' following Snodgrass and Corwin (1988) using the following two equations:

$$A' = 0.5 + \frac{(H - FA)(1 + H - FA)}{4H(1 - FA)} \quad \text{when H} \geq \text{FA and} \tag{1}$$

$$A' = 0.5 - \frac{(FA - H)(1 + FA - H)}{4FA(1 - H)} \quad \text{when H} < \text{FA,} \tag{2}$$

where H = hits and FA = false alarms. Equation 2 was used in calculations of the A' score for only a single participant (in the children with dyslexia group).

To further investigate potential differences between the strategies of listeners with dyslexia and listeners with average reading ability in terms of their inclination to respond *Ohio* rather than *North Carolina*, the responses were analyzed for the effects of listener bias. We used B''_D, a nonparametric measure of response bias proposed by Donaldson (1992) that is similar to the B'' measure by Snodgrass and Corwin (1988; see also Stanislaw & Todorov, 1999) except that it demonstrates better performance at low levels of discrimination. B''_D was computed using Equation 3:

$$B''_D = \frac{[(1-H)(1-FA)-HFA]}{[(1-H)(1-FA)+HFA]}. \qquad (3)$$

Dialect Sensitivity (A′ Measure)

Using SPSS Statistics (Version 21; IBM, Armonk, NY), a repeated measures analysis of variance was carried out on mean A' scores to investigate the within-subject effect talker sex (male, female) and the between-subjects effects listener group (dyslexia, average reading ability) and listener age (adults, children). A preliminary analysis indicated no significant effect of listener sex, $F(1, 72) = 0.317$, $p = .575$, $\eta_p^2 = .020$, so this variable was subsequently excluded from further consideration. Two main effects were significant. Listeners with average reading ability were significantly more sensitive to talker dialect than were listeners with dyslexia, $F(1, 76) = 27.58$, $p < .001$, $\eta_p^2 = .266$ (average reading ability: $M = 0.909$; dyslexia: $M = 0.807$), and adults were significantly more sensitive than children, $F(1, 76) = 15.24$, $p < .001$, $\eta_p^2 = .167$ (adults: $M = 0.877$; children: $M = 0.812$). As shown in Figure 1, listeners with dyslexia were less sensitive to talker dialect compared with listeners with average reading ability; of note is a comparatively greater variability in the responses of participants with dyslexia, particularly for children with dyslexia. The main effect of talker sex was not significant, $F(1, 76) = 0.17$, $p = .898$, $\eta_p^2 = .000$.

The two-way interactions involving talker sex were significant and subsequently were explored with post hoc t tests. The significant Listener Group × Talker Sex interaction, $F(1, 76) = 9.14$, $p = .003$, $\eta_p^2 = .107$, displayed in Figure 2, resulted from the fact that listeners with average reading ability showed greater sensitivity to male talkers ($M = 0.901$) than to female talkers ($M = 0.876$), whereas this pattern was reversed for listeners with dyslexia (male talkers: $M = 0.789$; female talkers: $M = 0.812$). However, paired t tests showed that the male–female differences were significant only for listeners with average reading ability, $t(39) = 4.01$, $p < .001$, and not for listeners with dyslexia, $t(39) = -1.50$, $p = .143$.

There was also a significant Listener Age × Talker Sex interaction, $F(1, 76) = 5.31$, $p = .024$, $\eta_p^2 = .065$. As illustrated in Figure 3, adult listeners were more sensitive to male talkers ($M = 0.886$) than to female talkers ($M = 0.867$), whereas the pattern was reversed for children, who were more sensitive to female talkers ($M = 0.821$) than to male talkers ($M = 0.803$). Paired t tests showed that the male–female differences were significant for adults, $t(39) = 2.39$, $p = .022$, but were not significant for children, $t(39) = -1.16$, $p = .253$. The remaining interactions were not significant,

Figure 1. Mean dialect sensitivity scores (A') for adult and child participants with average reading ability (AR) and adult and child participants with dyslexia (DYS). The error bars represent 1 *SE*.

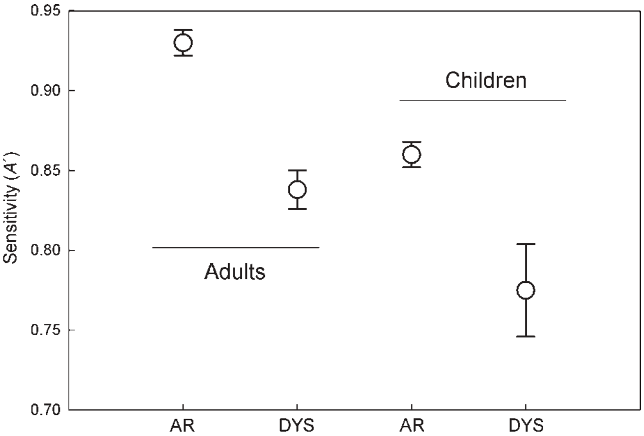


Figure 2. Mean dialect sensitivity scores (A') for participants with average reading ability (AR) and participants with dyslexia (DYS) as a function of talker sex. The error bars represent 1 *SE*.

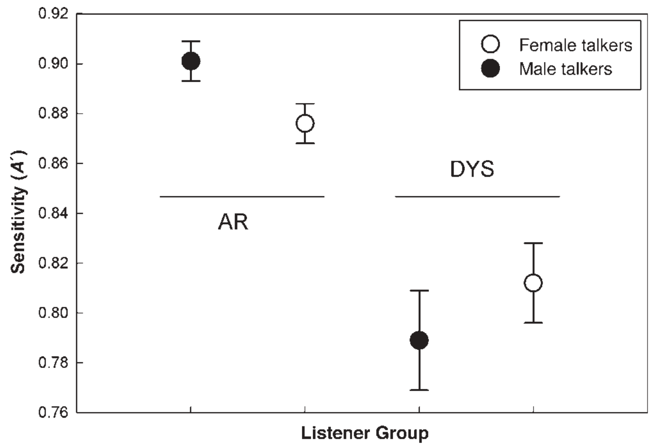
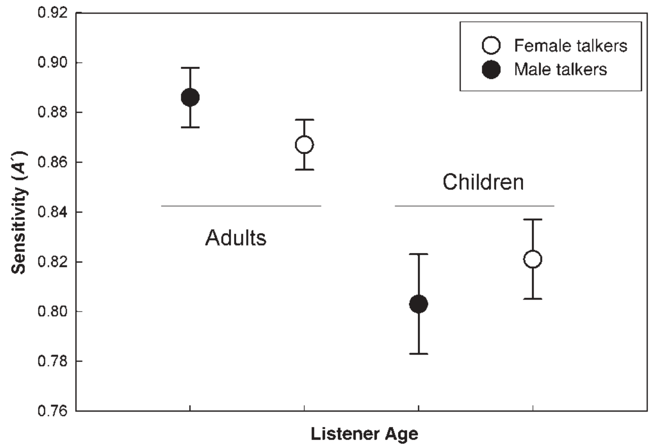


Figure 3. Mean dialect sensitivity scores (A') for adult and child participants as a function of talker sex. The error bars represent 1 *SE*.



including Listener Group × Listener Age, $F(1, 76) = 0.007$, $p = .936$, $\eta_p^2 = .000$, and Listener Group × Listener Age × Talker Sex, $F(1, 76) = 3.48$, $p = .066$, $\eta_p^2 = .044$.

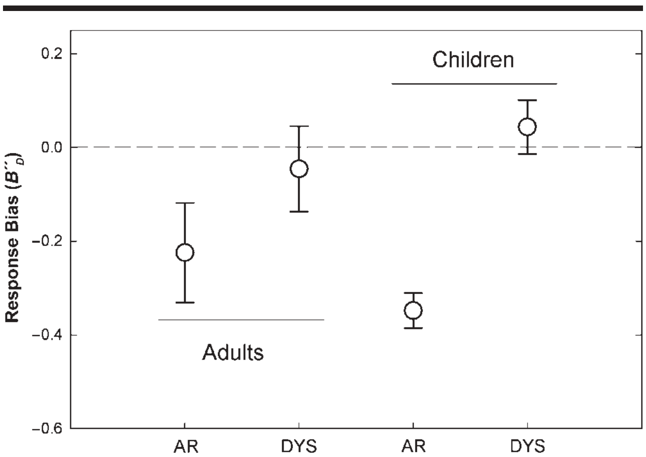
Response Bias (B''_D Measure)

The contribution of bias to making decisions about talker dialect reflects how liberal or conservative listeners are under uncertainty (Lynn & Barrett, 2014) and is a function of where each listener places his or her criterion for responding *target*. That is, in case of doubt, a liberal listener tends to respond that the ambiguous talker was from Ohio (the target) rather than from North Carolina (the foil). In signal detection theory terms (Macmillan & Creelman, 2005), by choosing a target rather than a foil, a liberal listener will show a negative bias. On the other hand, a conservative listener tends to respond that the talker was from North Carolina (i.e., choose a foil rather than a target), showing a positive bias. For the B''_D measure, values lie between −1 and +1. A zero value indicates no bias. Negative values are associated with a liberal bias (because the listener's criterion is shifted to the left of the two possible response distributions: target and foil), whereas positive values are associated with a conservative bias (because the response criterion is shifted toward the target distribution to the right). To reiterate, negative values indicate a bias toward responding *Ohio*, whereas positive values indicate a bias toward responding *North Carolina*.

Shown in Figure 4 are the results for response bias broken down by listener group and listener age. A repeated measures analysis of variance with the between-subjects factors listener group and listener age and the within-subject factor talker sex was used to assess possible differences in the response bias. The main effect of group was significant, $F(1, 76) = 11.71$, $p < .001$, $\eta_p^2 = .133$. There were important differences between the groups. Subsequent one-sample *t* tests showed that listeners with average reading ability had a liberal bias—that is, were significantly more likely to respond *Ohio*, $M = -0.286$, $t(39) = -5.078$, $p < .001$—whereas listeners with dyslexia were unbiased in their responses, $M = -0.001$, $t(39) = -0.018$, $p = .985$. A significant main effect of talker sex, $F(1, 76) = 19.93$, $p < .001$, $\eta_p^2 = .208$, indicated that talker sex influenced listeners' response bias. In particular, all listeners were significantly more likely to choose *Ohio* in response to a female talker, $M = -0.245$, $t(79) = -5.382$, $p < .001$, but were unbiased in response to a male talker, $M = -0.021$, $t(79) = -0.444$, $p = .658$. The main effect of listener age was not significant, $F(1, 76) = 0.044$, $p = .835$, $\eta_p^2 = .001$.

There was a significant Listener Age × Talker Sex interaction, $F(1, 76) = 7.07$, $p = .010$, $\eta_p^2 = .085$, which is illustrated in Figure 5. In terms of bias, adults were significantly more likely to choose *Ohio* in response to a female talker, $M = -0.171$, $t(39) = -2.595$, $p = .013$, but were unbiased in response to a male talker, $M = -0.080$, $t(39) = -0.999$, $p = .324$. Children's responses had the same overall pattern: a liberal bias in response to a female talker, $M = -0.319$, $t(39) = -5.191$, $p < .001$, and no bias in response to a male talker, $M = 0.037$, $t(39) = 0.709$, $p = .483$. The significant interaction arose because the difference in bias in response to male versus female talkers was significant for the children, $t(78) = 3.68$, $p < .001$, but not for the adults, $t(78) = 1.91$, $p = .060$. No other interactions were significant, including Listener Group × Listener Age, $F(1, 76) = 1.89$, $p = .173$, $\eta_p^2 = .024$; Listener Group × Talker Sex, $F(1, 76) = 2.53$, $p = .116$, $\eta_p^2 = .032$; and Listener Group × Listener Age × Talker Sex, $F(1, 76) = 0.36$, $p = .850$, $\eta_p^2 = .000$.

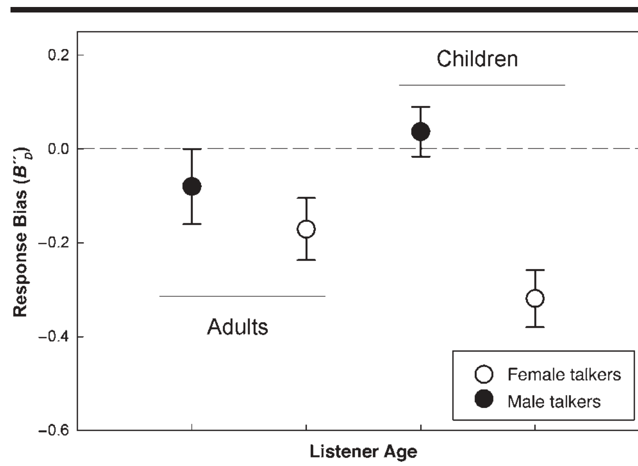
Figure 4. Mean response bias scores (B''_D) for adult and child participants with average reading ability (AR) and adult and child participants with dyslexia (DYS). Negative values represent liberal bias (i.e., a bias toward responding *Ohio*). The error bars represent 1 *SE*.



Correlations Between Dialect Categorization (A', B''_D) and Measures of Phonological Processing

Listeners' performance was further examined in relation to clinical assessment measures of phonological processing ability. Pearson's correlations were carried out

Figure 5. Mean response bias scores (B''_D) for adult and child participants as a function of talker sex. The error bars represent 1 *SE*.



separately on each of the four groups to determine the strength of the associations between dialect categorization measures and CTOPP-2 tests. Here, a positive correlation indicates that a better ability to categorize dialects is associated with a better ability to process phonological information.

For all groups, only scores on phonological memory tests (i.e., phonological memory composite, memory for digits, and nonword repetition) were strongly associated with dialect sensitivity (A'), and no significant correlations among other CTOPP-2 measures with A' scores were obtained (see Table 2). The strongest positive significant correlations among all three phonological memory tests with A' were for adults with dyslexia (Pearson's r ranging from .554 to .710). The correlations were also strong for children with average reading ability (ranging from .430 to .670) and moderately strong for adults with average reading ability (ranging from .249 to .550), but the two groups with average reading ability differed on phonological memory subtests. In particular, the correlations between phonological memory composite and A' scores were significant for both groups with average reading ability, whereas memory for digits scores significantly correlated with A' scores only for adults with average reading ability, and nonword repetition scores significantly correlated with A' scores only for children with average reading ability. The correlations for children with dyslexia, although positive, were weak (ranging from .145 to .394) and not significant. This outcome clearly differentiates children with dyslexia from the remaining groups, showing that their weaker sensitivity to dialect features is not significantly associated with their performance on phonological memory tests.

A similar analysis was carried out for B''_D. For both groups of listeners with dyslexia, no significant correlations among CTOPP-2 scores and B''_D scores were obtained. For listeners with average reading ability, the overall pattern was similar to that for A'. That is, for adults with average reading ability, B''_D scores were significantly correlated with the phonological memory composite and with the memory for digits scores; for children with average reading ability, B''_D scores were significantly correlated with phonological memory composite and with the nonword repetition scores (see Table 2). No significant correlations among any other CTOPP-2 measures with B''_D scores were obtained for any group with average reading ability.

In summary, the analyses for the groups with average reading ability revealed that both dialect sensitivity and response bias (i.e., listeners' greater likelihood to respond *Ohio* when uncertain) were significantly correlated with selected measures of phonological memory ability. However, for the groups with dyslexia, significant correlations between A' and phonological memory tests were obtained only for adults with dyslexia. No similar correlations were found for the children with dyslexia. Moreover, no significant correlations between B''_D and phonological memory tests were obtained for either group with dyslexia, consistent with the finding that listeners with dyslexia were not biased when making decisions about talker dialect.

Discussion

The current study builds on previous reports in the literature that listeners with dyslexia are deficient in the ability to recognize different voices of unfamiliar talkers in their native language (Perrachione, Del Tufo, & Gabrieli, 2011). We hypothesized that, compared with controls with average reading ability, adults with dyslexia would be less sensitive to dialect features in the speech of multiple talkers because perception of regional accents crucially depends on the ability to detect consistent fine-grained phonetic variations. Furthermore, the details of indexical information

Table 2. Correlations between measures of phonological ability (Comprehensive Test of Phonological Processing–Second Edition) and measures of dialect categorization (dialect sensitivity: A'; response bias: B''_D) for adults and children with dyslexia and adults and children with average reading ability (AR).

Participant	Phonological awareness	Elision	Blending	Phoneme isolation	Phonological memory composite	Memory for digits	Nonword repetition	Rapid symbolic naming composite	Rapid digit naming	Rapid letter naming
A' adults with dyslexia	.171	.432	−.099	.353	.710***	.554*	.596**	−.327	−.334	−.307
A' adults with AR	−.124	−.208	−.073	−.026	.550*	.446*	.249	.106	.078	.097
A' children with dyslexia	.176	.101	.096	.192	.394	.358	.145	−.054	−.017	−.070
A' children with AR	.250	.293	.242	.235	.624**	.430	.670**	.143	.411	−.172
B''_D adults with dyslexia	−.130	−.324	−.229	−.034	−.128	−.151	−.032	−.267	−.129	−.372
B''_D adults with AR	−.204	−.184	.099	−.242	.475*	.544*	.182	−.091	−.174	.036
B''_D children with dyslexia	.047	−.185	.227	.049	−.089	−.013	.322	−.216	−.005	−.427
B''_D children with AR	.351	.258	−.037	.412	.538**	.356	.524**	.123	.269	−.049

*$p < .05$. **$p < .01$. ***$p < .001$.

in talker dialect ought to be retained in working memory for association with underlying indexical (or episodic) representations (Goldinger, 1996, 1998; Nygaard & Pisoni, 1998). We expected listeners with dyslexia to be less efficient in utilizing dialect cues in accommodating talker variability due to both increased demands on working memory caused by the processing of speech produced by 40 different talkers and impaired access to stored phonological representations (Boets et al., 2013; Ramus & Szenkovits, 2008). Confirming our predictions, the study found that adults with dyslexia were limited in their ability to categorize talker dialect. Compared with adults with average reading ability, adults with dyslexia were significantly less sensitive to dialect features, and the distribution of their responses showed greater variability.

The same overall pattern was true for children. As expected, children with dyslexia were less sensitive to dialect than children with average reading ability. There was also a significant difference in performance between the child and adult groups in that children were uniformly less sensitive to dialect features than were the adults. The results for children with average reading ability are consistent with other reports in the literature demonstrating that processing talker information is more cognitively demanding for children than for adults (Levi & Schwartz, 2013) and that even older children are less efficient than adults in accommodating talker variability (Jacewicz & Fox, 2014). The current findings add to the mounting evidence that phonological processing skills are still maturing in late childhood and early adolescence (Hazan & Barrett, 2000).

The comparatively poorer performance of children with dyslexia in this study is highly suggestive of an underlying phonological deficit, which impedes their abilities to utilize talker normalization processes in the ways the children with average reading ability do. A related finding was reported for preschool children with specific language impairment, who demonstrated a weaker ability to perceive individual talker variations compared with their age-matched peers (Dailey, Plante, & Vance, 2013). In the context of the current study, the phonological deficit was manifested in children's less effective processing of indexical information. Some aspects of this deficit may be developmental in that they are related to slower development of phonological grammar—that is, the implicit rules or constraints that govern how sounds are assembled into words—in children with dyslexia (Marshall & Van Der Lely, 2009). Limited experience with regional variation in speech relative to adults is another contributing factor. Of relevance here is a study of younger children with average reading ability by Wagner, Clopper, and Pate (2014), who found that 5- to 6-year-olds were still in the process of mastering regional dialect as an indexical category and were not able to successfully separate their home dialect from another regional dialect. With regard to the current study, it may be the case that a slower development of phonological grammar in children with dyslexia also contributed to their limited ability to categorize indexical properties of speech, although this possibility remains to be tested in a focused design. It can be presumed that the locus of the poorer performance of the children with dyslexia was in the combined effects of deficient phonological ability; maturation of phonological processing skills; relative inexperience with regional accents, including delayed formation of indexical categories; and less effective talker normalization strategies.

Performance of listeners with dyslexia and listeners with average reading ability in the current study also differed in terms of response bias. In particular, listeners with average reading ability were significantly more likely to respond *Ohio* when uncertain about talker dialect, whereas listeners with dyslexia were unbiased in their responses. The lack of bias in listeners with dyslexia (both children and adults) clearly corresponds to their reduced dialect sensitivity. When the speaker sounded ambiguous, listeners with dyslexia were not inclined to choose one dialect over the other as listeners with average reading ability did. This outcome may to some extent reflect inherent differences between individuals with dyslexia and individuals with average reading ability associated with the presence or absence of dyslexia-related deficiencies. On the other hand, both listeners with dyslexia and listeners with average reading ability showed similar bias as a function of talker sex: Both groups were significantly more likely to choose *Ohio* in response to a female talker, and both were unbiased in response to a male talker. This result suggests that certain indexical features in female voices triggered a similar liberal response bias, eliminating the differences between the groups. We have no explanation for this curious result at present. Likewise, it is unclear why children (and not adults) were significantly more likely to respond *Ohio* to female talkers, as indicated by a significant Listener Age × Talker Sex interaction in the analysis of B''_D.

The fact that talker sex interacts with dialect categorization decisions merits some discussion. In particular, listeners with average reading ability were more sensitive to dialect in response to male talkers, whereas listeners with dyslexia did not benefit from differences in talker sex. Likewise, talker sex interacted with listener age so that adults were more sensitive to dialect in response to men, whereas children's decisions were not significantly influenced by the sex. We note that talker sex previously has been found to interact with dialect features in speech perception in listeners with average reading ability. In a study examining perceptual sensitivity to different dialects, perceptual ratings on same-sex pairs were higher than ratings on different-sex pairs (Clopper et al., 2006). McCloy, Wright, and Souza (2015) found that when listeners responded to target utterances in two different dialects under noisy conditions, male talkers were more intelligible than female talkers. This finding suggests that male speech may provide a more distinct set of acoustic features associated with regional variation that become more salient in challenging listening conditions. This may be due to the fact that men typically use more of the local dialect markers in their speech compared with women (e.g., Barbu, Martin, & Chevrot, 2014; Jacewicz et al., 2011; Labov, 1990). The current results provide further support for this view: Those listeners who showed significantly higher dialect sensitivity (i.e., listeners with average reading ability vs. listeners with dyslexia and adults vs. children) were also more sensitive to dialect differences when sentences were spoken by men.

The talker sex–related asymmetry found in the current study suggests that male productions may supply greater phonetic constancy with regard to socioacoustic features. The redundancy of dialect markers in male speech would place a smaller load on working memory components, facilitating dialect recognition in speech of multiple talkers. Mature phonological processing skills in adults seem to take advantage of this redundancy, and adults' listening strategies may include a form of pattern-recognition implementation, which would impose lower loads on working memory. However, a signal that is highly redundant for an adult may be only minimally redundant for a child (Mills, 1975), and older children's perceptual strategies may still use a different type of acoustic cue weighting that impedes their flexibility in attending to indexical features in speech. The less efficient strategies of children with average reading ability resulted in performance levels comparable to those in adults with dyslexia, whose inability to benefit from the indexical redundancy in male speech can be attributed to their deficient processing skills associated with their impairment.

It is noteworthy that the correlations between CTOPP-2 scores and A' scores were significant only for the phonological memory components, indicating that dialect sensitivity was most strongly associated with phonological memory abilities. This result is consistent with Perrachione, Del Tufo, and Gabrieli (2011), whose adults with dyslexia scored particularly low on phonological memory (i.e., on the nonword repetition subtest), which significantly correlated with their poorer voice recognition performance. However, unlike in Perrachione et al., the current participants must have also relied on implicit long-term memory, which underlies acquired knowledge of regional variation in speech. In the task at hand, the listeners were to associate the indexical nuances of the unknown talkers' voices with both phonological representations of speech sounds and indexical dialect-related information encoded in long-term memory through prior experience with regional variation.

The perceptual operations used to recognize the indexical features in unfamiliar voices of 40 talkers most certainly imposed a processing cost due to heavier working memory load, and the current task was demanding for adults with average reading ability. The significant correlations between CTOPP-2 scores and A' scores for adults with average reading ability and children with average reading ability are therefore hardly surprising. However, it needs to be underscored that adults with dyslexia must have also overcome their reduced ability to retain talker information in working memory in order to associate the indexical features with implicit long-term memory representation for dialect-related variations. Their low scores on phonological memory tests are thus predictive of their reduced dialect sensitivity, as evident in strong and significant correlations with A' scores. The lack of similar correlations for children with dyslexia may be explained by a range of developmental factors such as maturation of phonological processing skills, relative inexperience with regional accents, or delayed formation of indexical categories as discussed above. These additional variables make the direct relation between phonological memory scores and dialect sensitivity less straightforward.

In conclusion, given that participants with dyslexia in this study did demonstrate ability to categorize talker dialect, it is unlikely that the strong correlations between phonological memory and dialect sensitivity for adults with dyslexia indicate poorly specified representations due to memory impairment. It appears that differences in their performance compared with listeners with average reading ability are due to problems with accessing underlying phonological representations rather than to differences in those representations. Access to implicit long-term memory representations is most likely impeded because of less efficient operations in working memory, including deficiencies in utilizing talker normalization processes. It can be presumed that the access is hampered by increased processing costs associated with resolving phonetic and dialect-indexical differences among multiple talkers in working memory, including those components that are involved in talker category learning (Levi, 2014).

The current results carry several important clinical implications. First, they reinforce the need for more sensitive assessment tools to evaluate phonological processing abilities in dyslexia, including measures of indexical processing ability. Second, the results suggest that the influence of regional variation on phonological category formation in children with dyslexia may underlie some of the difficulties with accurate and fluent word recognition and poor spelling abilities. For example, talker–listener dialect mismatches or an extensive accentedness of input speech will likely lead to an increase in processing effort in children with dyslexia and interfere with their sound-to-letter mapping. Last, the current results suggest that multiple-talker social contexts (e.g., busy airports or restaurants) may impose an increase in cognitive load in individuals with dyslexia, leading to poorer performance on tasks involving reading and spelling.

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Appendix

Stimulus Sentences Used in the Dialect Categorization Task

Central Ohio: Male Talkers

1. Several years ago it was a very small town.
2. And now it's becoming a much larger city.
3. My son doesn't have a major yet.
4. My daughter played volleyball and softball.
5. I'm going to talk to you about my son Bradley.
6. We are involved in our college search right now.
7. We had a great time going up in Jim's van.
8. The drive home was very long; it was tiring.
9. And about a 2-hr wait in one spot.
10. The sun come out, which was nice.
11. It was Linguistics 201, I think.
12. Particularly in the region of the country where we are.
13. I'm told that I was born in 1937.
14. The next event was the move itself.
15. Met at church at a young adults' group.
16. Her aunt and uncle used to be the advisers of the group.
17. I guess she's a freshman in college next.
18. My dad was a sort of hobby farmer.
19. A side yard that was big enough to play baseball.
20. That he was going to move back to Italy.

Central Ohio: Female Talkers

21. My parents always had a business there.
22. Because my dad had had a nervous breakdown.
23. He ended up not going into the service.
24. The neighborhood was always a safe place to be.
25. I don't know why I don't like bees.

26. And I should tell you about my new kitten.
27. One shy one is medium and the other one is very outgoing.
28. And of course there is the barking beagle.
29. More ethnically diverse than it was back then, too.
30. My mother's house was sold last year.
31. *C* is my middle initial.
32. And so now I try not to use any middle initial.
33. And so I became a librarian.
34. It only lasted for 3 years.
35. We were married in October of 1977.
36. Our children are all on the tall side also.
37. Our oldest son lives in Salt Lake City.
38. The youngest works for the Washington Speakers Bureau.
39. Some people do not appreciate their family.
40. He comes to work and he cannot see.

Western North Carolina: Male Talkers

41. My mother was a school teacher for 42 years.
42. I had one brother; his name was John.
43. A lifetime of listening to my parents and grandparents.
44. And you know people still do that today.
45. I have a 20-year-old daughter named Paige.
46. My father came over here after the Second World War.
47. We did a program called vector analysis.
48. The boss superintendent sent me to Providence, Rhode Island.
49. Donna had the most beautiful wedding dress.
50. Exactly, precisely like the great Ellingberg wedding.
51. I was standing in a cafeteria line.
52. It was a fun place to go.
53. He was born in 1938.
54. She had to have me in a hospital.
55. Cassie's supposed to come home today, in fact.
56. Bryce is going to have surgery on his shoulder.
57. And I've done some other interesting things along the way.
58. Meant a lot of good things to me over the years.
59. I have no idea of how my mom and dad met.
60. We grew up and went to school together.

Western North Carolina: Female Talkers

61. My granddaughter was born 2 months after my mother died.
62. Four generations that I did not get.
63. Janet, the words are there in your head if you would just write them down.
64. Well, no, but I figured I could save it up.
65. I'm going to tell you about my middle daughter.

66. Eight baby copperheads under the blanket.
67. I got a master's degree in history.
68. I have seven grandchildren, and they are all very healthy.
69. My mother came from a family of eight.
70. Fifteen cents to get into a ball game.
71. I'm a retired banker of 25.5 years.
72. And we do horse-and-buggy weddings.
73. I was the middle of three children.
74. I guess you could say Indian-type herbs.
75. People here had never seen anything like it.
76. I can't think of a particular example.
77. I remember both my grandmothers very well.
78. My sister got me interested in genealogy.
79. I have three children: two boys and one girl.
80. And we each have a portion of this land.