Speaking Clearly for Children With Learning Disabilities: Sentence Perception in Noise

Ann R. Bradlow
Nina Kraus
Erin Hayes
Northwestern University
Evanston, IL

This study compared the speech-in-noise perception abilities of children with and without diagnosed learning disabilities (LDs) and investigated whether naturally produced clear speech yields perception benefits for these children. A group of children with LDs (n = 63) and a control group of children without LDs (n = 36) were presented with simple English sentences embedded in noise. Factors that varied within participants were speaking style (conversational vs. clear) and signal-to-noise ratio (–4 dB vs. –8 dB); talker (male vs. female) varied between participants. Results indicated that the group of children with LDs had poorer overall sentence-in-noise perception than the control group. Furthermore, both groups had poorer speech perception with decreasing signal-to-noise ratio; however, the children with LDs were more adversely affected by a decreasing signal-to-noise ratio than the control group. Both groups benefited substantially from naturally produced clear speech, and for both groups, the female talker evoked a larger clear speech benefit than the male talker. The clear speech benefit was consistent across groups; required no listener training; and, for a large proportion of the children with LDs, was sufficient to bring their performance within the range of the control group with conversational speech. Moreover, an acoustic comparison of conversational-to-clear speech modifications across the two talkers provided insight into the acoustic–phonetic features of naturally produced clear speech that are most important for promoting intelligibility for this population.

KEY WORDS: clear speech production, clear speech perception, children with learning disabilities, speech perception in noise, speech intelligibility

In order to improve speech intelligibility under adverse conditions, it may be more effective to modify the talker's speech production than to modify either the listener's speech perception or the acoustic properties of the speech signal (Picheny, Durlach, & Braida, 1985). This talker-based approach to speech intelligibility improvement may be particularly effective when multiple performance degrading factors are present, such as when the listening environment is noisy and the listener has a speech perception deficit. The overall goal of the present study was to pursue this approach to speech intelligibility enhancement for a broadly defined group of school-age children who were experiencing difficulties with their academic performance. In addition to providing basic information about the efficacy of this talker-based approach to speech perception enhancement for this population, a further goal of this study was to identify the specific acoustic–phonetic enhancements that were most beneficial for speech perception in this population. This information has the potential

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to contribute to the ongoing characterization of the speech perception deficits that may be related to the problems that interfere with the academic performance of some individuals in this population.

The literature on the speech perception abilities of children with language, learning, and reading disorders is diffuse in terms of the specific participant inclusion criteria applied across studies; however, a common finding of this research is that a subset of the children with impairments, regardless of the specific diagnostic category, show speech perception deficits relative to their peers without impairments (e.g., Bradlow et al., 1999; Elliott, Hammer, & Scholl, 1989; Kraus et al., 1996; Mody, Studdert-Kennedy, & Brady, 1997; Reed, 1989; Stark & Heinz, 1996; Sussman, 1993; Tallal & Piercy, 1974). Thus, a speech perception deficit seems to be a common characteristic across a wide range of diagnoses, even though the overall profiles of the various participant populations may be quite different. In particular, individuals in this broadly defined group of children with learning disabilities (LDs) often exhibit particular difficulty discriminating between speech sounds whose acoustic–phonetic properties are very similar (see Bradlow et al., 1999, for a summary). Nevertheless, the mechanism that underlies the observed perceptual deficit and the consequences of this deficit for continuous speech perception have yet to be fully described.

A separate line of research has demonstrated that listeners with speech perception deficits are disproportionately affected by degraded speech signals relative to listeners without speech perception deficits. For example, Kenyon, Leidenheim, and Zwillenberg (1998) compared performance on a speech discrimination test in noise and in quiet for listeners without hearing impairments and listeners with at least a 50-dB loss above 3000 Hz. They found a 33% and 5% decrease in perception in noise (relative to quiet) for the listeners with and without hearing impairments, respectively. Similarly, several studies have shown that non-native listeners show a sharper decline than native listeners in performance on speech perception tasks with increasing levels of signal distortion, either through the addition of more background noise or reverberation (e.g., Mayo, Florentine, & Buus, 1997; Meador, Flege, & MacKay, 2000; Nábèlek & Donahue, 1984). These studies provide evidence that various signal distortions, including background noise and reverberation, present particular difficulty for listeners with speech perception problems, including listeners with impaired hearing and from different language backgrounds. On the basis of these findings, we may expect that children with LDs who exhibit speech perception difficulties relative to their peers without LDs will show patterns of speech perception in quiet and in noise similar to those of other populations with speech perception difficulties. Indeed, it is commonly believed—and there is much supporting anecdotal evidence—that children with problems that interfere with academic achievement in mainstream school settings (including language, learning, or reading disorders) have particular difficulty with speech perception under the noisy listening conditions that are often encountered in a typical classroom. However, few studies have directly addressed this issue, and studies using sentence-length utterances and school-age participants are especially rare.

Chermak, Vonhof, and Bendel (1989) found that adults with LDs had poorer word identification in noise than a control group of adults without LDs. These authors also found that both the control group and the group of listeners with LDs had greater difficulty when the target words were masked by speech spectrum noise than when they were masked by competing linguistic strings; however, this masker-dependent decline in performance was greater for the adults with LDs than for the controls.

In a study with Dutch-speaking participants using meaningful Dutch sentences, Stollman, Kapteyn, and Sleeswijk (1994) found that the speech recognition thresholds in noise for children with impaired hearing and for children with impaired language abilities were significantly higher than for children and adults without hearing or language impairments. These authors also manipulated the time scale of their stimuli by expanding or compressing the recorded speech materials. They found that as the time-scale factor increased (i.e., as the speech was more compressed in time) the difference in speech reception threshold in noise between the participant groups increased; most notably, the performance of the children with either hearing or language impairments declined more sharply than that of the adults and children in the control group.

Finally, Elliot et al. (1979) found that children with LDs generally required a higher signal intensity than children without LDs in order to reach equivalent levels of performance on a monosyllabic word identification task. Furthermore, although both the control and disabled groups in this study showed greater difficulty for word recognition with an open-set response format relative to a closed-set response format, this decline in performance across response formats was greater for the children with LDs than for the children in the control group. However, contrary to the patterns shown in other studies (e.g., Chermak et al., 1989; Stollman et al., 1994), Elliot and colleagues did not find that the children with language and learning impairments were more adversely affected by noise than the children in the control group; rather, both groups showed similar performance decrements in noise relative to in quiet. Taken together, the findings from these studies indicate that factors that introduce difficulty into speech perception tasks, such as background noise, time compression, or response set size, generally have a greater effect on participants with impairments than on control participants without impairments.

The first specific goal of the present study was to directly investigate the abilities of children with LDs and of a control group of children without LDs to perceive sentence-length utterances when presented in differing levels of noise. The rationale behind the focus on sentence-length materials was based on the fact that the cognitive and linguistic processes involved in the perception of words in sentence context are quite different from those involved in the perception of isolated words, because of the availability of syntactic, semantic, and pragmatic information, which is not available from isolated syllables or words. The intelligibility advantage of words in sentences over words in isolation when presented in a noisy environment was originally demonstrated by Miller, Heise, and Lichten (1951) who interpreted this result as arising from the fact that access to the contextual information provided by the sentence helps the listener by narrowing the response alternatives. This finding was replicated by O'Neill (1957) using different test materials and a larger group of listeners and has since been widely acknowledged in the literature on speech intelligibility for both humans (with or without speech and hearing impairments) and machines (cf. Pisoni, 1997; Pisoni, Nusbaum, & Greene, 1985; Weismer & Martin, 1992).

Furthermore, there is some evidence that children with reading disabilities rely on contextual information more than do peers without impaired reading abilities. For example, using the experimental paradigm developed by Ganong (1980), which assesses a listener's bias toward a real-word rather than a nonsense-word response in a phoneme identification task, Reed (1989) showed that children with a reading disability allowed their knowledge of English words to influence their phoneme identification functions to a greater extent than children without reading disabilities. This result suggests that children with reading disabilities may develop spoken language processing strategies that compensate for their perceptual difficulties. Therefore, one might suspect that the speech perception difficulties in response to syllable- or word-sized stimuli exhibited by some children with language, learning, or reading disabilities may be attenuated when the children are tested with longer utterances where more contextual information is available. The results of Stollman et al. (1994) indicate that, contrary to this prediction, the sentence-in-noise perception abilities of Dutch-speaking children with either hearing or language impairments were poor relative to controls, suggesting that perhaps the children with impairments had greater difficulty with the memory-intensive task of sentence perception than their peers without impairments. We sought to replicate this finding with English-speaking children and to extend it by investigating whether some of the speech perception difficulties experienced by children with LDs could be overcome by naturally produced "clear" speech.

Several previous studies have shown that speech produced with an intentionally clear speaking style yields significant intelligibility improvements relative to conversational speech perception for adult listeners with impaired hearing and for adults without hearing impairments in quiet (Picheny, Durlach, & Braida, 1985), as well as in noise and reverberation (Payton, Uchanski, & Braida, 1994; Uchanski, 1988). The "clear speech effect" (i.e., the intelligibility advantage of clear speech over conversational speech as measured in percentage of key words correctly recognized) for these listeners is stable across studies at approximately 17–20 percentage points. These researchers have also identified several acoustic–phonetic markers of clear speech, including decreased speaking rate, vowel space expansion, increased frequency of word final stop releasing, and increased obstruent root mean square intensities (Picheney, Durlach, & Braida, 1986). Importantly, these studies have shown that it is the combination of multiple clear speech modifications that is responsible for the large clear speech intelligibility benefit. In particular, a series of studies on the individual contribution of the decreased speaking rate to the enhanced intelligibility of clear speech production has shown that the rate manipulation on its own is not sufficient to provide the intelligibility gain of clear speech (Krause, 2001; Picheney, Durlach, & Braida, 1989; Uchanski et al., 1996). Moreover, related work on lexical learning in children with specific language impairments has shown that input manipulations, such as naturally produced variations in speaking rate and prosody, which typically involve modifications to multiple acoustic–phonetic parameters, can have a positive influence on the ability of children with specific language impairments to produce novel words (Ellis Weismer & Hesketh, 1996, 1998). Given recent interest in the use of digital enhancement techniques in speech and language training procedures for children with LDs (e.g., Merzenich et al., 1996; Tallal et al., 1996), we wanted to investigate whether naturally produced clear speech with its multitude of acoustic–phonetic modifications that extend across an entire utterance would yield significant perception benefits for this population.

If children with LDs do perform better with clear than conversational speech, then detailed acoustic analyses of the naturally produced conversational-to-clear speech transformation could provide valuable information about the underlying perceptual deficit by highlighting specific acoustic–phonetic features of the signal that are spontaneously enhanced by this listener-oriented, stylistic variation in speech production. Subsequent parametric studies that investigate the perceptual benefit of individual enhancement strategies could help isolate acoustic characteristics that are problematic for connected speech perception by this population, and that should be the target of intervention strategies. Moreover, if naturally produced clear speech is an effective means of improving the speech perception by this population, then it may be worthwhile for teachers, parents, clinicians, and other caregivers who come into frequent contact with children with LDs to monitor their own speech in an effort to adopt a clear speaking style on a routine basis. A necessary first step toward achieving these goals is to establish that the intelligibility advantage of clear speech is robust for these listeners.

With these goals in mind, the present study was designed to test two specific hypotheses. First, we hypothesized that children with clinically diagnosed LDs would perform worse than children without LDs on a sentence-in-noise perception task. We wanted to perform a carefully controlled laboratory study that specifically looked at the perception of naturally produced, English sentence-length stimuli in noise so that we could assess whether the speech perception deficits that these children often exhibit with syllable- and word-sized stimuli extends to longer utterances where more contextual information is available to the listener. We also expected that children with LDs would be more adversely affected by a decreasing signal-to-noise ratio than children without LDs. Second, we hypothesized that children with and without LDs would all derive substantial benefit from the acoustic–phonetic cue enhancements that characterize naturally produced clear speech. Although we had no specific predictions regarding the relative sizes of the clear speech effects across the two groups of children, our hope was that any sentence-in-noise deficit for the children with LDs when presented with conversational speech stimuli could be overcome when presented with clear speech stimuli, at least to the extent that there would be no difference in performance between the group of children with LDs with clear speech and the group of children without LDs with conversational speech. Such a result would indicate that the overt manifestations of the underlying perceptual deficit can be overcome by the spontaneous articulatory adjustments that talkers naturally make in response to compromised communicative settings. Although this result on its own would not provide conclusive information regarding the *nature* of the underlying deficit, it would provide information about the communication conditions that can promote more accurate spoken language processing by listeners with speech perception deficits.

Method

Participants

A group of 99 school-age children served as study participants: 36 (15 girls and 21 boys) were classified as having normal development, and 63 (18 girls and 45 boys) were classified as having an LD. All these children were enrolled in a comprehensive study of speech sound discrimination abilities, academic achievement, and neurophysiologic responses to speech stimuli in children with and without LDs—the "Listening, Learning, and the Brain" project—that is currently under way in the Auditory Neuroscience Laboratory in the Department of Communication Sciences and Disorders at Northwestern University. As part of this larger study, a psychoeducational test battery that focused on verbal abilities was administered to each child. This test battery included portions of the Woodcock–Johnson Psycho-Educational Battery (Woodcock & Johnson, 1977), the Woodcock-Johnson Psycho-Educational Battery–Revised (Woodcock & Johnson, 1989), and the Wide Range Achievement Test, 3rd edition (Wilkinson, 1993). Table 1 lists the specific tests included in this study-internal test battery. In addition, the children's language development and academic achievement were assessed via a detailed parent questionnaire. For a child to be included in the group of children without LDs—the control group—there had to be no history of language, learning, or attention problems, as indicated by responses on the parent questionnaire, and the child had to score within or above normal limits on the psychoeducational test battery. Prior to entry into the study, the children with LDs had been formally clinically diagnosed as having an LD ($n = 49$) or a combination of LD and attention deficit disorder ($n = 14$). Furthermore, these participants performed worse than the control participants on the study-internal psychoeducational test battery. We refer to the children in this group as "children with LDs," or LD. Table 2 lists the group mean scores and standard deviations for the psychoeducational tests that were administered to all children. As shown in this table, the scores from the group of children with LDs were all significantly lower (at the $p < .05$ level) than the scores from the control group.

In addition to the tests shown in Table 1, the standard test battery for all participants in the "Listening, Learning and the Brain" project includes a test of the participant's ability to discriminate synthetic CV syllables along three /da/-/ga/ continua: the first consists of a 40-ms formant transition period followed by a 60-ms steady state period; the second has a 10-ms release burst superimposed on the 40-ms transition period; and the third is identical to the second but presented to the participants embedded in broad-band, white noise (for additional details, see Bradlow et al., 1999; Cunningham,

Table 1. Portions of the Woodcock–Johnson Psycho-Educational Battery, the Woodcock–Johnson Psycho-Educational Battery–Revised, and the Wide Range Achievement Test, 3rd edition, that were included in the study-internal psycho-educational test battery.

Auditory processing	A weighted sum of scores from three subtests: Incomplete Words: Participant must identify words that contain one or more missing phonemes. Sound Patterns: Participant must determine whether two streams of complex sounds are identical. Sound Blending: Participant must blend a stream of syllables or phonemes into a word.
Memory for words	Participant must recall verbatim a series of increasingly long strings of unrelated words.
Cross-out	A visual match-to-sample task that provides a measure of processing speed and sustained attention.
Listening comprehension	Participant must listen to a spoken passage and demonstrate comprehension by providing the last word.
Reading	Participant must read aloud a series of increasingly difficult individual words.
Spelling	Participant must use a pencil and paper to spell a series of increasingly difficult individual words.
Brief Cognitive Scale (also known as the "Broad Cognitive Ability, Brief Scale.")	Determines participant's overall verbal, mental aptitude. A weighted sum of scores from two verbally administered subtests: Quantitative Concepts: Participant must answer questions concerning vocabulary and concepts associated with the field of mathematics. No calculations are required. Antonyms and Synonyms: Participant is asked to state a word whose meaning is the opposite of the aurally and visually presented target word (antonyms) or the same as the target word (synonyms).

Nicol, Zecker, Bradlow, & Kraus, 2001; Kraus et al., 1996). Of the 99 participants in the present study, the group of children with LDs exhibited significantly higher discrimination thresholds than the control group when tested on all three continua,"burst-less" /da/-/ga/: $t(97) = 1.687$, $p = .047$ (1-tailed); /da/-/ga/ with 10-ms burst in the quiet: $t(96) = 3.005$, $p < .005$ (1-tailed); /da/-/ga/ with 10-ms burst in noise: $t(95) = 3.002$, $p < .005$ (1-tailed). For the test with the enhanced continuum (with the 10-ms burst), 1 child from the control group was not available for testing; for the test in noise, 1 child from each of the two groups was not available for testing.

The children were all also tested on their ability to discriminate synthetic CV syllables along a stop-glide continuum going from /ba/ to /wa/. Stimuli in this continuum consisted of a formant transition period followed by a steady state period, with no release burst. The duration of the formant transition period varied from 10 to 40 ms. (For additional details, see Bradlow et al., 1999; Kraus et al., 1996.) Discrimination thresholds along this continuum did not differ across the two groups of children, $t(97) = .724$, $p = .155$ (1-tailed), indicating that the group of children with LDs exhibited a selective speech perception deficit such that they had difficulty with a spectral contrast (i.e., /da/-/ga/) but not with a temporal contrast (i.e., /ba/-/wa/). This establishes that the children with LDs had a stimulus-dependent speech perception deficit that was independent of a general cognitive deficit relative to the control group.

Across both groups, the age range was limited to 8.1–12.5 years. For the group of children with LDs, the mean age was 10.29 years (SD = 1.16 years); for the control group the mean age was 10.43 years (SD = 1.32 years.) All children had normal hearing (thresholds better than 20 dB HL for 500–8000 Hz) and intelligence (Brief Cognitive Scale scores no less than 85). Of the 63 children with LDs, 21 had a history of a speech or language delay reported by the parent questionnaire, and 9 were on medication for their learning problem at the time of testing.

Stimuli

Stimuli consisted of four sets of sentences from the Revised Bamford-Kowal-Bench Standard Sentence Test. These sentences are slightly modified versions of the original Bamford-Kowal-Bench (BKB) sentences that were developed for use with British children (Bench & Bamford, 1979). The revised set was developed by the Cochlear Corporation for use with American children. The sentences are all simple declaratives with either three or four key words. Each list of 16 sentences includes 50 key words. For this study, 4 of the original 21 sentence lists (Lists 7, 8, 9, and 10) were selected based on their equivalent intelligibility scores for children without hearing impairments (Bamford & Wilson, 1979). These lists, with the key words underlined, are given in the Appendix.

Two talkers (one man, age 33 years, and one woman, age 40 years) were recorded producing these sentences in a sound-treated booth in the phonetics laboratory in the Department of Linguistics at Northwestern University. Both were native talkers of General American English with no known speech or hearing impairment at the time

Table 2. Group means and standard deviations (in parentheses) for the tests that were administered to all children.

Test	LD only (n = 49)	LD/ADD (n = 14)	LD comb. (n = 63)	Control (n = 36)	LD comb. vs. control (2-tailed, t test)
Auditory Processing	88.39 (9.81)	89.14 (6.69)	88.49 (9.01)	97.94 (10.21)	$p < .001$
Memory for Words	95.00 (12.98)	92.93 (8.19)	95.18 (13.35)	106.28 (11.93)	$p < .001$
Cross Out	102.77 (11.91)	102.29 (15.28)	102.77 (13.12)	111.33 (12.93)	$p < .01$
Listening Comprehension	113.00 (20.28)	108.57 (16.22)	110.80 (19.25)	119.19 (17.68)	$p < .05$
Reading	93.63 (12.33)	91.57 (8.05)	94.31 (12.11)	114.06 (11.42)	$p < .001$
Spelling	90.94 (11.80)	88.07 (2.24)	91.94 (12.87)	111.00 (12.62)	$p < .001$
Brief Cognitive Scale	106.74 (14.24)	103.36 (1.04)	106.62 (14.12)	120.64 (12.05)	$p < .001$

Note. LD = learning disability; LD/ADD = a combination of LD and attention deficit disorder; LD comb. = combined LD and LD/ADD groups; Control = children without impairments.

of recording. They read the sentences from a printed list while speaking into a microphone that fed directly into the sound card (SoundBlaster Live) of a desktop computer. Recording was done on a single channel at a sampling rate of 16 kHz using the Praat speech analysis software package (developed at The Institute of Phonetic Sciences at the University of Amsterdam, copyright by Paul Boersma and Paul Weenink). The input level was adjusted to ensure maximum gain without exceeding the dynamic range of the recording system.

Following methods used in previous studies of clear speech (Krause, 2001; Payton et al., 1994; Picheny et al., 1985, 1986; Uchanski, 1988), both talkers produced the sentences in both conversational and clear speaking styles. For the conversational speaking style, the talkers were told to read at their normal pace without any particular attention to clarity. The talkers were told to imagine that the intended listener of these recordings was someone highly familiar with their voice and speech patterns. For the clear speaking style, the talkers were told to read the sentences as if talking to a listener with a hearing loss or someone from a different language background.

After the recording sessions, the digital speech files were segmented into sentence-length files. The root mean square amplitude of each of the digital speech files was then rescaled to 65 dB SPL, thus ensuring that all files would play out at equivalent overall levels. At the time of presentation to the participants, the sentences were mixed with broadband (0–8000 Hz) white noise using Tucker Davis audio equipment in conjunction with special-purpose software that controlled the stimulus presentation and signal-to-noise ratio. Within a test session, each participant heard each sentence only once. Signal-to-noise ratio (–4 dB vs. –8 dB) and speaking style (conversational vs. clear) were factors that varied within participants. In order to keep the test time manageable, each participant responded to the full set of stimuli as produced by only one talker. The order of presentation of the four sentence lists was counterbalanced to ensure that any effect of speaking style could not be attributed to order of presentation of the conversational and clear sentence lists, nor to an interaction of sentence list and signal-to-noise ratio. The order of signal-to-noise ratio conditions was not varied across participants; rather, the –8 dB signal-to-noise ratio always came second so that any practice effect would be counteracted by the more difficult signal-to-noise ratio (which was presumed to be more powerful than any practice effect). Furthermore, in order to keep the number of conditions manageable, we did not vary speaking style across the lists; that is, Lists 7 and 9 were always the conversational speech lists and Lists 8 and 10 were always the clear speech lists. This feature of the overall design assumes equal intelligibility across the particular sentences in each of the lists (see Bamford & Wilson, 1979; Hanks & Johnson, 1998, for empirical support for this assumption). The distribution of participants across the various sentence presentation conditions for each of the two talkers is shown in Table 3.

Acoustic Analysis of the Stimuli

In order to verify that the talkers did indeed produce two distinct styles of speech in response to our instructions, we performed a series of acoustic analyses of the stimuli. The specific acoustic–phonetic parameters that we targeted in this analysis were selected based on previous findings regarding the acoustic–phonetic differences between conversational and clear speech (Picheny et al., 1986). The analyses of these stimuli also served as a basis for speculating about the specific clear

Table 3. Distribution of participants across sentence presentation conditions for the lists produced by the male and female talkers.

Sentence presentation condition			Male talker		Female talker		
			Control	LD	Control	LD	Total
A	−4 dB SNR −8 dB SNR	List 7—Conv List 8—Clear List 9—Conv List 10—Clear	5	7	5	10	27
B	−4 dB SNR −8 dB SNR	List 8—Clear List 7—Conv List 10—Clear List 9—Conv	4	9	4	7	24
C	−4 dB SNR −8 dB SNR	List 9—Conv List 10—Clear List 7—Conv List 8—Clear	4	10	4	3	21
D	−4 dB SNR −8 dB SNR	List 10—Clear List 9—Conv List 8—Clear List 7—Conv	5	10	5	7	27
		Total	18	36	18	27	99

Note. Control = children without LDs; LD = children with learning disabilities including both LD only and LD/ADD subgroups; SNR = signal-to-noise ratio; Conv = conversational speech sentences; Clear = clear speech sentences.

speech modifications that may be responsible for any clear speech intelligibility benefit exhibited by the participants in the present study in response to the sentence-in-noise perception test. For all of the acoustic analyses, we performed the measurements on the exact sentences that were used in the sentence-in-noise perception test; that is, we compared the measurements from the conversational speech sentences (from Lists 7 and 9) to the measurements from the clear speech sentences (from Lists 8 and 10) for each of the two talkers.

Table 4 shows a comparison of measurements from each of the two talkers' productions of clear and conversational sentences on 11 different acoustic parameters. To measure overall speaking rate, we compared the average sentence duration for each of the talkers when producing the full set of 32 conversational speech sentences and when producing the full set of 32 clear speech sentences. Both talkers showed a large increase in sentence duration for the clear speaking style relative to the conversational speaking style. However, this sentence duration increase, as a percentage of the average conversational speech sentence duration, was much smaller for the male talker (52%) than for the female talker (116%), indicating that the female talker decreased her speaking rate from conversational to clear speech far more than the male talker.

In order to assess the extent to which the observed duration increases for clear speech were due to an increase in the frequency and duration of pauses as opposed to individual segment duration increases, we counted the number of pauses in each sentence and recorded each pause's duration. We defined a pause as any period of silence of at least 5 ms long, excluding silent periods before word initial stop consonants where it was impossible to separate a true pause from the stop closure. Picheny et al. (1986) used a 10-ms criterion; however, we found that this longer duration cut-off excluded many silent periods for which there was a clear auditory impression of an intentional pause. In addition to the pause frequency and duration measures, we also calculated the average pause-to-sentence duration ratio for individual sentences. Both talkers increased the number of pauses, the average pause duration and the pause-to-sentence duration ratio in clear speech relative to conversational speech. However, the magnitude of the female talker's clear speech changes on these measures was greater than the magnitude of those of the male talker.

Next, we counted the number of times that the talkers produced an alveolar flap for an underlying voiceless alveolar stop (/t/). Alveolar flapping is a common articulatory "weakening" process in American English that can cause the neutralization of underlying lexical contrasts; for example, in conversational speech "writer" and "rider" often become homophones due to flapping of the medial alveolar in "writer." Although there were not many opportunities for flapping to occur (eight in conversational and nine in clear speech sentences), both talkers reduced their rate of flapping in clear speech relative to conversational speech. In fact, the male talker showed no instances of flapping in his clear speech productions. A related measure was the frequency with which word final stop consonants had an audible release. In American English, it is common for word final stop consonants to be unreleased particularly when the following word begins with a stop consonant or the word is utterance-final. Again the materials did not present a large number of word final stop consonants in an environment where we might expect them to be unreleased (35 in each of the conversational and clear sentence lists). Nevertheless, as shown in Table 4, both talkers decreased their rates of word final stop consonant unreleasing in clear speech relative to conversational speech, with the male talker actually releasing all word final stop consonants in clear speech.

Another acoustic–phonetic parameter that has been suggested as an important factor for intelligibility is the consonant-to-vowel intensity ratio (e.g., Gordon-Salant, 1986; Hazan & Simpson, 1998, 2000; Kennedy, Levitt, Neuman, & Weiss, 1998; Krause, 2001; Montgomery & Edge, 1988). In order to assess the extent to which the two talkers in the present study increased the ratio of consonant power to the power in a following vowel, we selected a set of 13 words that were common to the set of conversational sentences and to the set of clear speech sentences. In this manner, we were able to control for segment-inherent differences in intensity across the conversational and clear speech items. The specific items used for this comparison are given in Table 5. For the stop consonants, the power was measured in the release burst. For fricatives and vowels, the power was measured over the entire duration of the segment. Consonant-to-vowel intensity ratios were then calculated as the root mean squared power in the consonant (stop release burst or fricative) minus the root mean squared power in the vowel. As shown in Table 4, although the two talkers differed considerably in their overall consonant-to-vowel intensity ratios, both showed an increase in consonant-to-vowel intensity ratio for clear speech relative to conversational speech, with the female talker showing a larger increase than the male.

To get a measure of the pitch (i.e., fundamental frequency) characteristics of conversational and clear speech in our stimulus database, we measured the overall pitch mean and range for each sentence in each of the two speaking styles for each talker. Consistent with other studies (Krause, 2001; Picheny et al., 1986), we found that both talkers showed an increase in pitch mean and range for clear speech relative to conversational speech. As shown in Table 4, the female showed a larger pitch mean increase than the male, but the male showed a larger pitch range increase than the female.

Finally, we measured the acoustic vowel spaces for each of the two talkers in each of the two speaking styles. Several studies have shown that clear speech vowels are produced with more extreme articulations than conversational speech vowels, with the consequence that individual vowel categories are kept more acoustically distinct from each other and are therefore less likely to lead to cross-category confusion for the listener (e.g., Bradlow, 2002; Johnson, Flemming, & Wright, 1993; Krause, 2001; Moon & Lindblom, 1994; Picheny et al., 1986). In order to control for the effects of surrounding consonants and word-level stress on vowel formant frequencies, we selected a set of monosyllabic words that occurred in both the conversational and clear speech sentences (see Table 5). First and second formant frequencies were measured in each

Table 4. Acoustic analysis of the conversational (Conv.) and clear speech sentences as produced by the male and female talkers.

		Male talker			Female talker		
	Acoustic measurement	**Conv.**	**Clear**	**Diff.**	**Conv.**	**Clear**	**Diff.**
1.	Average sentence duration (s)	1.303	1.974	+0.671 (51.49%)	1.527	3.296	+1.769 (115.84%)
2.	Total number of pauses	1	25	+24	4	50	+46
3.	Average pause duration (ms)	2.5	11.9	+9.4	7.8	26.2	+18.4
4.	Average pause-to-sentence duration ratio (%)	0.12	4.26	+4.14	0.66	12.58	+11.92
5.	Alveolar flapping	6/8	0/9	—	6/8	1/9	—
6.	# word final stops released	30/35	35/35	+5	27/35	31/35	+4
7.	Word initial CVR (dB)	−4.73	−3.46	+1.27	−10.09	−8.34	+1.75
8.	F0 mean (Hz)	128	136	+1.12 semitones	158	217	+5.43 semitones
9.	F0 range (Hz)	321	460	+6.23 semitones	158	220	+5.81 semitones
10.	Vowel space range in F1 (mels)	386.66	409.77	+23.11	400.47	406.62	+6.15
11.	Vowel space range in F2 (mels)	720.03	842.87	+122.84	701.76	885.01	+183.25

Note. Numbers in parentheses are the clear–conversational difference (Diff.) as a percentage of the conversational measurement; CVR = consonant-to-vowel intensity ratio.

of these words. These measurements were converted from the Hertz scale to the perceptually motivated mel scale (Fant, 1973) according to the following equation: $M = (1000/\log 2)\log[(F/1000) + 1]$, where M and F are the frequencies in mels and Hertz, respectively. We then calculated the range in F1 and F2 covered by these vowels for each talker in each style. As shown in Table 4, both talkers increased both F1 and F2 range for the clear relative to the conversational speech vowel spaces. Both talkers also showed larger proportional increases in F2 range than in F1 range. Although the female talker showed a larger clear speech increase in F2 range than the male talker, the opposite pattern was observed for the increase in F1 range (the male's clear speech increase in the F1 dimension was larger than the female's). Nevertheless, given the greater clear speech vowel space expansion in the F2 dimension relative to the F1 dimension for both talkers, the overall clear speech vowel space expansion for the female talker was greater than for the male talker.

In summary, the acoustic–phonetic analysis of the conversational and clear speech sentences in this study showed qualitatively similar patterns of clear speech production across the two talkers. For both talkers, the conversational-to-clear speech modification involved a decrease in speaking rate, an increase in the number and duration of pauses, less alveolar flapping, more final stop releasing, a greater consonant-to-vowel intensity ratio, a higher mean pitch, a wider pitch range, and an expanded vowel space. Nevertheless, there were some differences between the degree to which each of the two talker's clear speech productions exhibited these specific acoustic–phonetic features. The female talker modified her speaking rate and increased the frequency and duration of interword pauses to a greater extent than the male talker. The female talker also showed a greater increase in F0 mean for clear speech than the male, and the female talker's overall clear speech vowel space expansion was greater than the male's. However, the male talker was more likely than the female talker to avoid reduction processes such as alveolar flapping and unreleased final stop consonants, and the male talker showed a greater increase in pitch range for clear speech than the female talker. These intertalker differences in clear speech production provided the basis for interpreting any talker-dependent intelligibility differences in the sentence-in-noise perception test.

Procedure

Participants were seated in a sound-treated booth directly facing a loudspeaker (Baby Advent II) that was positioned 4.5 feet from the participant's chair on a table with a height of 43 inches. An experimenter was seated in the booth with the participant. The sentences were presented to the participant via the loudspeaker, and the participant's task was to repeat orally what she or he heard. The stimulus presentation level—measured at the participant's chair—was on average 62 dB SPL. The experimenter recorded the number of key words that were correctly reported by the participant on prepared answer sheets. Participants could take as long as they needed to respond; however, each sentence was presented only once.

Table 5. Items used to measure the consonant-to-vowel intensity ratios and vowel formant frequencies.

Consonant-to-vowel intensity ratios			Vowel formant frequencies		
Word	Conv.	Clear	Word	Conv.	Clear
dog	List 7, #2	List 10, #7	dog	List 7, #2	List 10, #7
came	List 7, #2	List 8, #2	came	List 7, #2	List 8, #2
she	List 7, #4	List 8, #13	she	List 7, #4	List 8, #13
bus	List 7, #9	List 8,#12	ball	List 7, #11	List 8, #7
ball	List 7, #11	List 8, #7	book	List 7, #13	List 8, #1
girl	List 7, #13	List 8, #15	road	List 7, #16	List 10, #8
book	List 7, #13	List 8, #1	she	List 9, #4	List 10, #3
very	List 7, #14	List 10, #14	three	List 9, #5	List 8, #15
boy	List 9, # 2	List 10, #4	his	List 9, #8	List 10, #11
she	List 9, #4	List 10, #3	milk	List 9, #15	List 10, #12
shoes	List 9, #9	List 8, #14			
some	List 9, #15	List 10, #16			
milk	List 9, #15	List 10, #12			

Note. Conv. = conversational speech sentences.

After each trial, the experimenter pushed a button on a custom-made button box to elicit the next trial.

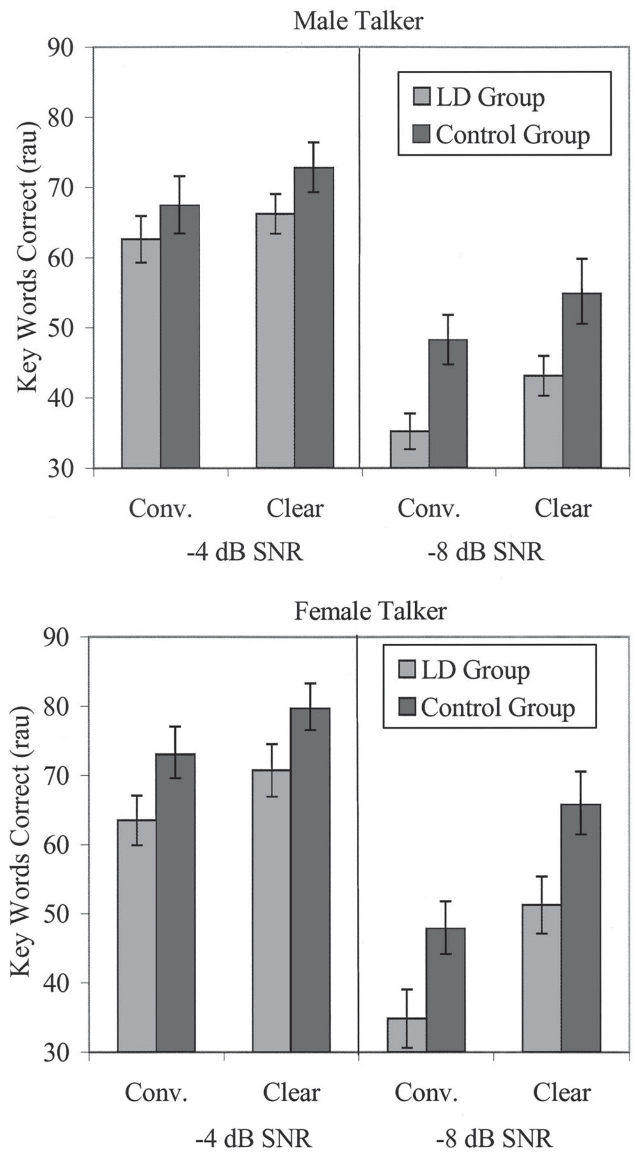
Results

Each participant received a key word correct score out of a possible total of 50 for each of the four sentence lists. The scores were converted to percentage correct scores and then converted to rationalized arcsine transform units (rau; Studebaker, 1985). This transformation places the scores on a linear and additive scale, thus facilitating meaningful statistical comparisons across the entire range of the scale. The transformed scores for each participant were then coded as rau scores for each of the four conditions: –4 dB signal-to-noise ratio conversational style, –4 dB signal-to-noise ratio clear style, –8 dB signal-to-noise ratio conversational style, and –8 dB signal-to-noise ratio clear style.

Figure 1 shows the average sentence perception scores in each of the four conditions for the group of children with LDs and the control group that were presented with the stimuli produced by the male (left panel) and female talker (right panel). As seen in these plots, the effects of speaking style and signal-to-noise ratio were quite robust for both listener groups. That is, both listener groups performed worse in the –8 dB signal-to-noise ratio condition than in the –4 dB signal-to-noise ratio condition, and both listener groups performed better in the clear speech condition than in the conversational speech condition. Furthermore, in all conditions, the control group of listeners performed better than the group of listeners with LDs, and this pattern was consistent across both talkers.

These impressions were supported by a four-factor repeated-measures analysis of variance with signal-to-noise ratio (–4 dB vs. –8 dB) and speaking style (conversational vs. clear) as within-participants factors and listener group (learning disabled vs. control) and talker (male vs. female) as between-participants factors. The main effects of listener group, signal-to-noise ratio, and speaking style were all highly significant: $F(1, 95) = 8.75$, $p < .005$, $\eta^2 = .05$ for listener group; $F(1, 95) = 389.65$, $p < .0001$, $\eta^2 = .23$ for signal-to-noise ratio; $F(1, 95) = 98.215$, $p < .0001$, $\eta^2 = .04$ for speaking style. The main effect of talker was not significant. There was a significant two-way interaction between signal-to-noise ratio and listener, $F(1, 95) = 6.42$, $p = .01$, $\eta^2 = .004$. Post hoc analyses showed that this interaction was due to a significantly greater drop in performance from the –4 dB to the –8 dB signal-to-noise ratio for the children with LDs relative to the control children (24.75 rau and 19.05 rau for the learning-disabled and control groups, respectively; Fisher's PLSD, $p < .02$). There also was a significant two-way interaction between speaking style and talker, $F(1, 95) = 11.53$, $p < .001$, $\eta^2 = .004$. This interaction was due to a significantly greater clear speech benefit for the stimuli produced by the female talker than for those produced by the male talker (11.99 rau and 5.86 rau for the female and male talkers, respectively; Fisher's PLSD, $p < .001$). In this regard, it is important to note that despite the different rates of speech across the two talkers in the conversational speech style (as shown in Table 4), there was no significant difference in intelligibility across the two talkers in this style. The greater clear speech benefit for the female talker was

Figure 1. Key words correct score for the control children (solid bars) and children with learning disabilities (striped bars) in both speaking style (conversational and clear) and both signal-to-noise ratio (–4 dB and –8 dB) conditions. Data for participants who responded to the sentences produced by the male and female talker are shown on the top and bottom, respectively.

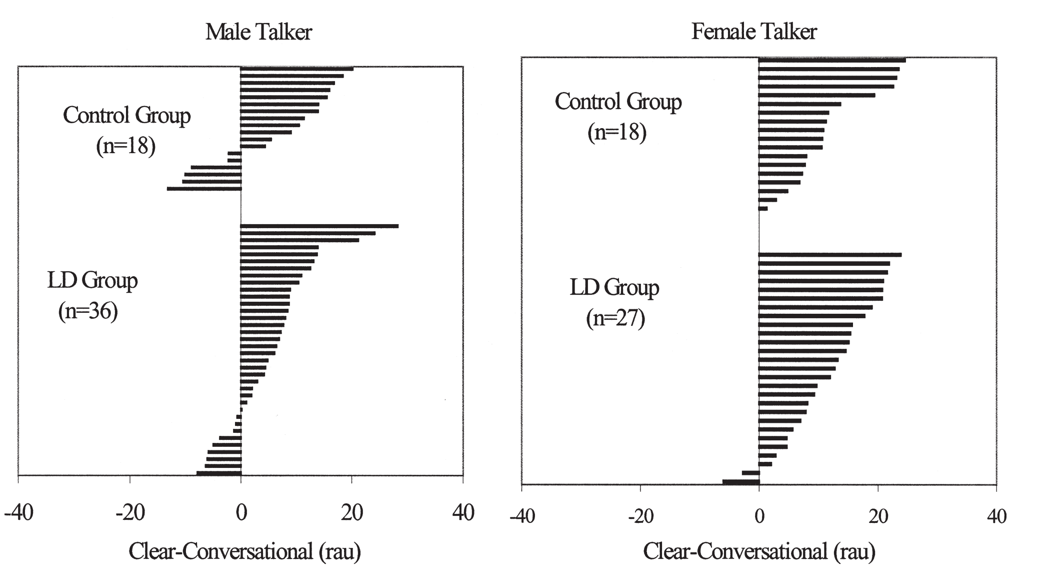


due entirely to a significant difference between the clear speech intelligibility scores for the two talkers, $t(97) = 2.816$, $p < .05$. The two-way interaction between speaking style and signal-to-noise ratio also was significant, $F(1, 95) = 14.50$, $p < .0001$, $\eta^2 = .005$, due to a greater clear speech benefit for the –8 dB than for the –4 dB signal-to-noise ratio (11.83 rau and 5.46 rau for the –8 dB and –4 dB signal-to-noise ratios, respectively; $F(1, 98) = 14.76, p < .001, \eta^2 = .064$. The three-way interaction between signal-to-noise ratio, speaking style, and talker also was significant, $F(1, 95) = 4.75$, $p < .05$, $\eta^2 = .002$. Pairwise comparisons showed that for the female talker, the clear speech effect was significantly greater in the –8 dB than in the –4 dB signal-to-noise ratio condition (mean difference = 10.06 rau), $t(44) = 4.82$, $p < .001$ (2-tailed), whereas for the male talker the clear speech effect did not differ significantly across signal-to-noise ratio conditions. None of the other interactions was significant.

In summary, these data showed that the group of children with LDs had greater difficulty perceiving sentences in noise than the control group. This sentence-in-noise perception deficit was consistent across the two talkers. However, the group of children with LDs was more adversely affected by a decrease in signal-to-noise ratio than was the control group. Furthermore, both groups derived a significant perceptual benefit from the acoustic–phonetic enhancements afforded by naturally produced clear speech. The magnitude of this clear speech effect for the control group and the group of children with LDs was 8.8% and 9.2% on the rau scale, respectively. For both groups, this clear speech effect was dependent on the talker (greater for the female than for the male talker) and the signal-to-noise ratio (greater for the –8 dB than for the –4 db signal-to-noise ratio). Finally, pairwise comparisons showed no significant differences between the average clear speech perception score for the group of children with LDs and the average conversational speech perception score for the control group. This pattern was observed across both the –4 dB and –8 dB signal-to-noise ratio conditions and across both talker conditions. In other words, when presented with sentences in naturally produced clear speech, performance on the sentence-in-noise perception task by the group of children with LDs was at the same level of performance as the control group when presented with the conversational speech sentences.

Figure 2 shows a comparison of the magnitude of the clear speech effect for individual participants in both the male and female talker conditions. The clear speech effect was calculated as the difference between the scores for the clear and conversational speaking style conditions averaged across the two signal-to-noise ratio conditions. As shown in this figure, the vast majority of individual participants in both talker conditions showed a substantial clear speech effect. Indeed, the vast majority of both the children with LDs (82.5%) and the control children (83.3%) derived some benefit from this talker-related modification, indicating that the clear speech effect for both groups was quite robust. Furthermore, a large proportion (38%) of the children with LDs improved their performance by over 10.5%—the average difference between the two groups'

Figure 2. Clear-conversational speech perception difference score for individual participants in both listener groups. Data for participants who responded to the sentences produced by the male and female talker are shown on the left and right, respectively.

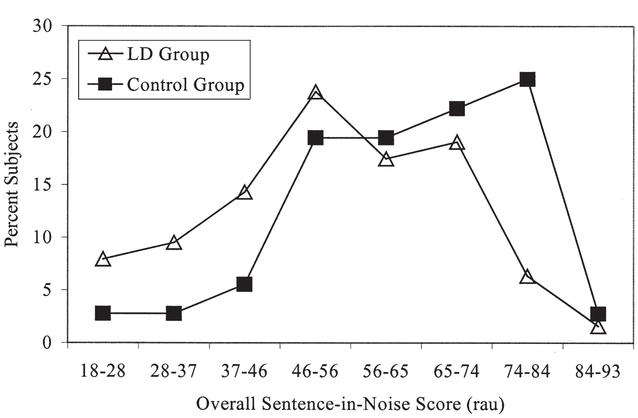


performance levels on this task—indicating that for many of the participants with LDs, the magnitude of the clear speech benefit is sufficient to bring their performance within the range of performance of the control group.

In order to gain additional insight into the prevalence of the sentence-in-noise perception deficit in the group of children with LDs, we examined the distribution of scores within each of the two participant groups. For each participant, we calculated an overall sentence-in-noise perception score by averaging the key word correct scores across all four conditions (–4 dB signal-to-noise ratio conversational style, –4 dB signal-to-noise ratio clear style, –8 dB signal-to-noise ratio conversational style, and –8 dB signal-to-noise ratio clear style). Figure 3 shows the distributions of these scores for the two participant groups. As seen in these plots, although both groups include individuals with scores across a broad range (resulting in a nonsignificant chi-square value = 10.64, p = .16), the scores for the children with LDs were roughly evenly distributed around 56% on the rau scale (skewness coefficient = –.146), whereas the scores for the children in the control group were skewed toward the high end of the scale (skewness coefficient = –.520). This pattern of score distribution for the two groups suggests that relatively poor sentence-in-noise perception was more common in the group of children with impairments than in the control group, but performance on this test does not by itself sharply separate the two populations.

As noted above, 21 of the children with LDs had a history of a speech or language delay. An examination of these 21 individual participants' overall sentence-in-noise perception revealed a broad range of scores covering the entire distribution of scores represented in Figure 3 (M = 57, SD = 19, minimum = 18, maximum = 87). Additionally, there were 9 children with LDs who were on medication for their learning problem at the time of testing. The scores of these 9 children also covered a broad range. This indicates that neither history of a speech or language delay nor current medication is likely to have had a big effect on overall sentence-in-noise perception.

Figure 3. Distribution of overall sentence-in-noise perception scores for all participants in both listener groups.



Given the wide distribution of overall sentence-in-noise perception scores across both groups, we wondered whether the ability to benefit from clear speech and a favorable signal-to-noise ratio depended on the baseline, conversational speech sentence score rather than on diagnostic category (i.e., presence or absence of a learning problem). Specifically, we wondered whether participants from both groups who performed poorly with conversational speech would exhibit a general speech-processing deficit to the extent that their performance remained poor even with the enhanced clear speech signals. This effect would be reflected in positive correlations between the conversational speech sentence-in-noise scores and the clear minus conversational and –4 dB minus –8 dB difference scores. Alternatively, these correlations could be negative, indicating that the benefit of the enhanced signal diminishes with better conversational speech perception scores (i.e., no additional information is accessed through the enhanced signal). In fact, as shown in Table 6, the data showed no significant correlations between conversational speech sentence-in-noise perception and the clear minus conversational difference score for either participant group. In other words, the magnitude of the intelligibility advantage of clear speech across individuals was apparently not related to the baseline, conversational speech perception score. Similarly, there was no correlation between conversational speech sentence-in-noise perception and the –4 dB minus –8 dB signal-to-noise ratio difference score for either group.

Finally, in order to gain a more comprehensive view of the pattern of perceptual abilities exhibited by these participants, we examined the relationships between the conversational speech sentence-in-noise perception scores and other measures of these participants' perceptual abilities that were obtained as part of the "Listening, Learning, and the Brain" project. The measures of interest were discrimination thresholds along the three synthetic /da/-/ga/ speech continua and the measures from portions of the Woodcock–Johnson Psycho-Educational Battery, the Woodcock-Johnson Psycho-Educational Battery–Revised, and the Wide Range Achievement Test, 3rd edition (see Table 1). The correlations between these measures and the conversational sentence-in-noise score within each of the two participant groups are shown in Table 6. The data showed no significant correlations between discrimination thresholds along the synthetic speech continua (presented in either quiet or noise) and conversational speech-in-noise perception. For the control group, the data showed a significant positive correlation (p < .05) between conversational

Table 6. Correlations between the conversational sentence-in-noise perception scores and various other measures for the children with learning disabilities (LD), including both LD only and LD/ADD subgroups and the control children (control).

Correlation with conversational sentence-in-noise score	LD		Control	
	Correlation	*p*	Correlation	*p*
Clear minus conv. difference	−.196	*ns*	−.069	*ns*
−4 dB minus −8 dB difference	−.014	*ns*	−.196	*ns*
/da/-/ga/ in quiet JND	−.038	*ns*	.034	*ns*
/da/-/ga/ enhanced in quiet JND	.099	*ns*	−.117	*ns*
/da/-/ga/ enhanced in noise JND	−.210	*ns*	−.305	*ns*
Auditory Processing	−.037	*ns*	.428	.009
Memory for Words	.159	*ns*	.307	*ns*
Cross Out	.262	.039	.380	.021
Listening Comprehension	.218	*ns*	.412	.012
Reading	.102	*ns*	.379	.022
Spelling	.034	*ns*	.107	*ns*
Brief Cognitive Scale	.348	.005	.335	.046

Note. JND = just-noticeable-difference score/discrimination threshold.

sentence-in-noise perception and performance on all but two (Memory for Words and Spelling) of the seven tests in the psychoeducational battery. However, for the children with LDs, there was a significant positive correlation ($p < .05$) between conversational sentence-in-noise perception and performance on just two (Cross Out and the Brief Cognitive Scale, which measures general intelligence) of the seven tests in the battery.

Given the group difference in Brief Cognitive Scale scores (shown in Table 2) and the significant correlations within each group between Brief Cognitive Scale score and conversational sentence-in-noise perception (shown in Table 6), we further examined the relationship between overall cognitive function and sentence-in-noise perception. This analysis showed a significant positive correlation between Brief Cognitive Scale and sentence-in-noise perception within each group (LD group: correlation = .357, $p < .005$; control group: correlation = .362, $p < .05$) as well as across all participants (correlation = .442, $p < .0001$). Furthermore, an analysis of covariance with Brief Cognitive Scale as the covariate showed a nonsignificant main effect of Group (LD vs. Control) on overall sentence-in-noise perception. The two-way interaction of Group × Brief Cognitive Scale also was not significant. This analysis therefore indicates that sentence-in-noise perception was closely related to overall cognitive function. In contrast, we found no relationship between Brief Cognitive Scale and the magnitude of the clear speech benefit. That is, there was no correlation between Brief Cognitive Scale and the clear-conversational difference score and, as discussed above (and shown in Figures 1 and 2), there was no group difference on the average clear-conversational difference score. Both groups showed a clear speech benefit of approximately 9 points on the rau scale.

Discussion

The results of this study revealed patterns of sentence-in-noise perception that can inform our understanding of the speech perception deficits in children with LDs and suggest ways of enhancing speech communication in real-world settings for these children. The first finding was that the group of children with LDs performed worse overall than the control group of children without LDs. Furthermore, the group of children with LDs was more adversely affected by a decreasing signal-to-noise ratio than was the control group. This pattern of results is similar to patterns found for various other special populations, including listeners with hearing impairments (e.g., Kenyon et al., 1998) and from different language backgrounds (e.g., Mayo et al., 1997; Meador et al., 2000; Nábèlek & Donahue, 1984). Furthermore, it is consistent with previous work with similar populations (e.g., Chermak et al., 1989; Stollman et al., 1994). This finding suggests that factors that contribute to speech perception difficulties, including both signal-dependent factors such as background noise, reverberation, or time-compression and listener-dependent factors such as a hearing, language, or learning impairment, interact in such a way that the detrimental effects of one factor are compounded by the addition of another performance-detracting factor.

The results of this speech perception test with sentence-length utterances also demonstrated that the speech perception deficits that often are present in the broadly defined population of children with LDs include difficulty with the perception of meaningful sentences. This finding is consistent with Stollman et al.'s (1994) study of Dutch speaking children with hearing or language impairments. Moreover, our correlational analyses suggested that the skills and processes involved in sentence-in-noise perception and in isolated syllable discrimination (in quiet and in noise) may not be directly related. However, the data showed a relationship between overall cognitive function—as measured by the Brief Cognitive Scale (a measure of overall verbal, mental aptitude)—and sentence-in-noise perception, suggesting that accurate spoken sentence processing likely involves a wide range of cognitive and linguistic skills. (See Table 1 for additional details on the Brief Cognitive Scale.)

The data also indicated that poor performance on this sentence-in-noise perception task was not a defining feature of a learning impairment. As shown in Figure 3, overall sentence-in-noise scores for individuals in both groups covered a broad range, demonstrating that some children with LDs perform (unexpectedly) well on this task, and some children without LDs perform (unexpectedly) poorly on this task. Thus, rather than serving as a diagnostic for identifying a child with a learning problem, poor sentence-in-noise perception should be viewed as part of a constellation of auditory perceptual deficits that may or may not be present in an individual. This pattern of group mean differences despite substantially overlapping distributions is consistent with numerous other studies that have revealed groupwise differences across a wide range of auditory perception tasks with this population (e.g., Bradlow et al., 1999; Elliot et al., 1979; Kraus et al., 1996; Tallal, 1980) and should be taken as a note of caution regarding unjustifiable conclusions about the nature of the underlying deficit (for additional discussion of this point, see Farmer & Klein, 1995; Klein & Farmer, 1995; Martin, 1995; Rosen, van der Lely, & Adlard, 2000).

Although these data do not identify the precise mechanism that underlies the speech perception problems of the population of interest in this study, they provide information regarding the real-world communication situations that are most likely to impede accurate speech perception. Specifically, these data provide empirical evidence that the speech perception difficulties that are often experienced by children with LDs may be especially problematic in noisy listening environments, such as are often encountered in a typical classroom.

The second major finding of the present study was the beneficial effect of clear speech for both groups. A large proportion of individuals in both groups derived a substantial speech perception benefit from naturally produced clear speech, and for many of the children with LDs this clear speech benefit was sufficient to bring them within the range of performance of the control group with conversational speech. Furthermore, the magnitude of the clear speech benefit was stable at approximately 9 rau units for all children regardless of group (LD or control) or overall cognitive function (Brief Cognitive Scale score). The data also showed that the clear speech effect was greater for the –8 dB signal-to-noise ratio than for the –4 dB signal-to-noise ratio. This speaking style by signal-to-noise ratio interaction suggests that the strength of the performance-enhancing effect of clear speech may be sufficient to counteract the compounding effects of multiple performance-detracting factors, such as a learning-impairment and the presence of background noise. The finding of a substantial clear speech effect for this population is particularly encouraging because it identifies a relatively simple, cost-free, and immediately effective method for enhancing speech perception for these children.

In addition to the speaking style by signal-to-noise ratio interaction, the data in this study also showed a speaking style by talker interaction. Both of the talkers who produced the conversational and clear sentences used in the test of sentence-in-noise perception evoked a significant clear speech effect for both groups of listeners, suggesting that the clear speech effect does not necessarily require any training on the part of either the talker or the listener. Nevertheless, the magnitude of the clear speech effect in response to the female talker's productions was significantly greater than the clear speech effect in response to the male talker's productions. Furthermore, this difference in clear speech intelligibility was observed despite the fact that there was no difference between the talkers in terms of their conversational speech intelligibility. That is, the male and female talkers' conversational speech intelligibility scores were not significantly different. In other words, despite that fact that the female talker had a slower rate of conversational speech than the male (see Table 4), the listeners found each of the two talkers to have equivalent baseline, conversational speech intelligibility. In contrast, the female talker's clear speech intelligibility was significantly greater than that of the male talker, resulting in an overall greater clear speech benefit for the female talker than for the male talker. On the basis of the acoustic analyses of the conversational and clear speech sentences across the two talkers, we can infer which of the specific acoustic–phonetic enhancement features of clear speech were particularly effective in promoting speech perception accuracy for the population of interest in this study. In so doing, we can also suggest guidelines for clear speech production by talkers who have frequent contact with children in this population.

The acoustic analysis of the conversational and clear speech sentences produced by each of the talkers (summarized in Table 4) indicated that probably the most salient difference between clear speech production by the female and male talkers was with respect to overall speaking rate. The female talker slowed down her speaking rate to a far greater degree than did the male talker (52% vs. 116% lengthening in overall sentence duration for clear speech relative to conversational speech), and her strategy for achieving this decrease in speaking rate involved a substantial increase in the frequency and duration of interword pauses. The acoustic measurements also indicated that the female and male talker differed noticeably in the magnitude of the increase in pitch mean, in the extent to which they expanded their vowel spaces, and in the degree to which the consonant-to-vowel intensity ratio increased for clear speech relative to conversational speech. On all three of these parameters, the female talker's clear speech modification was greater in magnitude than the male talker's, although the intertalker differences on these parameters were not quite as large as the intertalker differences in the conversational-to-clear speech rate and pausing modifications. For the remaining parameters (pitch range, alveolar flapping, and final consonant releasing; see Table 4) there was less difference between the talkers.

This pattern of intertalker differences in the production of clear speech in conjunction with the intertalker difference in the size of the evoked clear speech effect for the listeners—despite equivalent conversational speech intelligibility—suggests that modifications to the temporal characteristics of the signal play a particularly important role in enhancing its overall intelligibility. Other important intelligibility enhancing features appear to be articulatory precision and effort, as indicated by the expanded vowel space; raised average pitch; and increased consonant-to-vowel intensity ratio of the female talker's clear speech production. In contrast, certain other features of clear speech, including the increase in pitch range and the elimination of reduction processes such as alveolar flapping and final consonant releasing, appear to be less important for enhancing its overall intelligibility for children with and without LDs. With respect to providing guidelines for effective clear speech production for parents, teachers, clinicians, and others who have frequent occasions to talk with children in noisy environments, it seems that it is well worth the effort to simply "speak clearly," paying particularly careful attention to reducing overall speaking rate.

In order to identify with certainty those acoustic–phonetic features of clear speech that are responsible for its enhanced intelligibility and those signal-related features that are most vulnerable to perceptual disruption in the population of children with LDs, we need carefully controlled, parametric studies in which each individual feature is manipulated in isolation from the others. Several studies have adopted this approach and have investigated the perceptual effects of digitally modified speech (Gordon-Salant, 1986; Hazan & Simpson, 1998, 2000; Krause, 2001; Merzenich et al., 1996; Picheny et al., 1989; Tallal et al., 1996; Uchanski et al., 1996) for a variety of listener populations, including adults with and without impaired hearing, nonnative listeners, and children with language and learning impairments. These studies have investigated the separate and combined effects of manipulating the temporal characteristics of the speech signal in a manner that resembles the temporal modifications of naturally produced clear speech and the intensity relationship between consonants and following vowels in a manner that resembles the increased consonant-to-vowel intensity ratio of naturally produced clear speech. Although this approach has achieved some success in enhancing intelligibility, it has not yet been quite as effective as naturally produced clear speech, suggesting that a key feature of naturally produced clear speech is the combination of individual enhancement strategies.

On the basis of the findings from the present study, we can conclude that a particularly effective means of enhancing speech perception under adverse listening conditions for children with and without LDs is to modify the talker's speech production. Although this approach has the disadvantage of treating the symptom rather than the underlying cause, its major advantages are threefold: it is cost free, it requires no listener or talker training, and it is almost universally effective.

Acknowledgments

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Contact author: Ann Bradlow, Northwstern University, Department of Linguistics, 2016 Sheridan Road, Evanston, IL 60208-4090. E-mail: abradlow@northwestern.edu

Appendix. Revised Bamford-Kowal-Bench (BKB) sentence lists that were used in this study, with the key words underlined.

BKB List 7

1. The children dropped the bag.
2. The dog came back.
3. The floor looked clean.
4. She found her purse.
5. The fruit is on the ground.
6. Mother got a saucepan.
7. They washed in cold water.
8. The young people are dancing.
9. The bus left early.
10. They had two empty bottles.
11. The ball is bouncing very high.
12. Father forgot the bread.
13. The girl has a picture book.
14. The orange was very sweet.
15. He is holding his nose.
16. The new road is on the map.

BKB List 8

1. The boy forgot his book.
2. A friend came for lunch.
3. The match boxes are empty.
4. He climbed his ladder.
5. The family bought a house.
6. The jug is on the shelf.
7. The ball broke the window.
8. They are shopping for cheese.
9. The pond water is dirty.
10. They heard a funny noise.
11. The police are clearing the road.
12. The bus stopped suddenly.
13. She writes to her brother.
14. The football player lost a shoe.
15. The three girls are listening.
16. The coat is on a chair.

BKB List 9

1. The book tells a story.
2. The young boy left home.
3. They are climbing the tree.
4. She stood near her window.
5. The table has three legs.
6. A letter fell on the floor.
7. The five men are working.
8. He listened to his father.
9. The shoes were very dirty.
10. They went on a vacation.
11. The baby broke his cup.
12. The lady packed her bag.
13. The dinner plate is hot.
14. The train is moving fast.
15. The child drank some milk.
16. The car hit a wall.

BKB List 10

1. A dish towel is by the sink.
2. The janitor used a broom.
3. She looked in her mirror.
4. The good boy is helping.
5. They followed the path.
6. The kitchen clock was wrong.
7. The dog jumped on the chair.
8. Someone is crossing the road.
9. The mailman brought a letter.
10. They are riding their bicycles.
11. He broke his leg.
12. The milk was by the front door.
13. The shirts are hanging in the closet.
14. The ground was very hard.
15. The buckets hold water.
16. The chicken laid some eggs.