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Categorical Perception of Speech by Children With Specific Language Impairments

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Abstract

Previous research has suggested that children with specific language impairments (SLI) have deficits in basic speech perception abilities, and this may be an underlying source of their linguistic deficits. These findings have come from studies in which perception of synthetic versions of meaningless syllables was typically examined in tasks with high memory demands. In this study, 20 children with SLI (mean age = 9 years, 3 months) and 20 age-matched peers participated in a categorical perception task. Children identified and discriminated digitally edited versions of naturally spoken real words in tasks designed to minimize memory requirements. Both groups exhibited all hallmarks of categorical perception: a sharp labeling function, discontinuous discrimination performance, and discrimination predicted from identification. There were no group differences for identification data, but children with SLI showed lower peak discrimination values. Children with SLI still discriminated phonemically contrastive pairs at levels significantly better than chance, with discrimination of same-label pairs at chance. These data suggest that children with SLI perceive natural speech tokens comparably to age-matched controls when listening to words under conditions that minimize memory load. Further, poor performance on speech perception tasks may not be due to a speech perception deficit, but rather to a consequence of task demands.

Keywords

speech perception; specific language impairment; children/language

The purpose of the present investigation was to examine categorical perception of speech by children with specific language impairments (SLI). These children experience language learning difficulties despite having normal hearing and normal nonverbal intelligence with no obvious articulatory or neurological deficits (Leonard, 1998). Although children with SLI are impaired in many aspects of language, including morphology and syntax, impairments in auditory processing have been hypothesized to be a possible underlying cause of language impairments (e.g., Eisenson, 1972). The nature of these putative difficulties remains an open question, however. For example, Tallal and colleagues have argued that children with SLI have a deficit in processing rapidly changing auditory information (Tallal & Piercy, 1973, 1974, 1975; Tallal, Stark, Kallman, & Mellits, 1981). Leonard and colleagues have argued

that children with SLI have a generalized slowing of sensory processing across modalities (Leonard, 1998; Leonard, McGregor, & Allen, 1992; Miller, Kail, Leonard, & Tomblin, 2001). Gathercole and Baddeley (1990) have argued that children with SLI have reduced storage for phonological material in working memory. Finally, Stark and Heinz (1996a, 1996b) have argued that children with SLI have inadequately specified phonological representations in long-term memory. Whatever the underlying nature of the auditory or phonological processing difficulty, its effects on language acquisition would be profound. Children who are less able to process acoustic or linguistic information will have more difficulty extracting statistical regularities from the input language, including word boundaries and form class, which will lead to difficulties at higher levels of language representation (e.g., Leonard, 1998).

To examine potential auditory processing deficits in children with SLI, researchers have used a variety of methods, including temporal order judgment (TOJ) tasks, just noticeable difference (JND) tasks, phoneme identification tasks, and categorical perception tasks. Although all of these tasks have found that children with SLI are not as facile with auditory or phonological stimuli as are typically developing children, they differ in the types of information they reveal about potential deficits. Each of these tasks is discussed in this article, along with information that can be gleaned from their results.

In TOJ tasks, listeners are presented with pairs of stimuli in one of four possible orders (1–1, 1–2, 2–1, 2–2). The listener's task is to identify and order the constituent stimuli. Pairs of stimuli typically vary along two separate dimensions—duration of stimuli and duration of silence between stimuli (interstimulus interval [ISI]). In 1965, Lowe and Campbell used this method to show that children with SLI have deficits in auditory temporal discrimination. They asked children to listen to two tones with a very short ISI and report whether they heard one or two tones. Children with SLI did not differ from control children in the ISIs needed to detect two separate tones. However, they needed much longer ISIs to correctly report the order in which the tones appeared. Tallal and Piercy (1973) replicated this finding with pure tones and then extended the work in 1974 to include synthetic vowels [e] and [æ] and consonant–vowel (CV) syllables [ba] and [da]. Children with SLI successfully reported the order of vowels but not the order of CV syllables. Tallal and Piercy suggested that children with SLI might have difficulty processing the rapidly changing formant transitions characteristic of consonants. However, their subsequent work (Tallal & Piercy, 1975) with steady-state vowel–vowel (VV) sequences [e–i] and [æ–i] revealed a similar pattern of results. Children with SLI had difficulty ordering both VV and CV sequences at short durations, but were unimpaired at longer durations. Taken together, these findings suggest that the difficulty experienced by children with SLI is due to the short duration and successive nature of the stimuli rather than the rapidly changing formant transitions. Nevertheless, Tallal and colleagues concluded that children with SLI have a temporal processing deficit affecting their ability to recognize rapidly changing acoustic elements (Merzenich et al., 1996; Tallal et al., 1996).

In JND tasks, listeners are presented with pairs of stimuli and must determine whether they are the same or different. One member of the pair is a clear exemplar of a particular speech sound, while the second member of the pair differs along one or more relevant acoustic

dimensions. This provides a measure of the smallest acoustic difference that can be discriminated. Using this task, Elliott and colleagues (Elliott & Hammer, 1988; Elliott, Hammer, & Scholl, 1989) found that children with language impairments require greater acoustic difference than children with normal language (NL) development to be able to discriminate synthetic [ba]–[pa] and synthetic [ba]–[da]–[ga]. They suggested that poorer auditory discrimination might lead to phonetic misperceptions (e.g., “ball” for “doll”), thereby leading to language learning difficulties. However, it should be noted that some of the children with language impairments in that study also had clinically significant articulation impairments. Consequently, these findings may reflect the processing abilities of children with speech impairments, language impairments, or both.

In phoneme identification tasks, listeners hear examples of two phonetic units to which they have been trained to respond differentially, typically by pressing buttons on a response pad. This research has shown that in addition to having difficulty processing shorter duration speech sounds, children with SLI are further hindered by spectral similarity among speech sounds. Building on previous work examining perceptual deficits related to short stimulus durations (Tallal & Piercy, 1974, 1975), Stark and Heinz (1996a, 1996b) used identification and TOJ tasks to examine perception of vowels and consonants by children with language impairments. Stark and Heinz (1996b) varied duration and spectral similarity between two synthetic pairs of vowel stimuli: [i]–[a] and [e]–[æ]. On the identification task, they found that children with language impairments could easily distinguish spectrally dissimilar vowels [i] and [a] regardless of duration, but had difficulty with spectrally similar vowels [e] and [æ] at both long and short durations. Those children who passed the identification portion then participated in a TOJ task. The results for [i]–[a] showed that children with language impairments were less able to resolve the temporal order at both long and short durations. As in previous studies (e.g., Elliott & Hammer, 1988), 9 of the 24 children with language impairments in this study failed the Templin-Darley Test of Articulation (Templin & Darley, 1969). Consequently, one cannot conclude whether difficulty resolving the temporal order of vowel sounds is difficult for children with articulation impairments or language impairments, or the combination of both impairments.

In their other study, Stark and Heinz (1996a) examined identification and TOJ of synthetic CV syllables [ba] and [da] varying in formant transition durations. In that study, they directly examined the role of articulation difficulties and language impairment on perception of these CV syllables. They separated the children with language impairments into those with both expressive and receptive impairments (LI–ER; $n = 21$) and those with just expressive impairments (LI–E; $n = 11$), based on expressive and receptive language scores from the Clinical Evaluation of Language Fundamentals—Revised (CELF–R; Semel, Wiig, & Secord, 1989). Of these children with LI, 10 of the 21 LI–ER children and 6 of the 11 LI–E children had articulation difficulties. First, when language impairment was considered independent of articulation impairment, children with LI–ER were significantly poorer than age-matched children in their ability to identify [ba] or [da], even at the longest transition durations. In contrast, the LI–E children did not differ from the age-matched children in this respect. Children with both language and speech impairments (including both LI–E and LI–ER) were significantly more likely than children with only language impairments (without speech impairments) to have difficulty identifying the [ba]–[da] syllables. As in the vowel

study, those children who passed the identification portion proceeded on to the TOJ task, including 9 of 21 children with LI-ER, 8 of 11 children with LI-E, and 17 of 22 age-matched children. Of these children who could identify CV syllables with 80-ms formant transition durations (who may or may not have had concomitant articulation difficulties), children with LI-E were less able than age-matched children to resolve the temporal order at all formant transition durations (30, 40, 50, 60, 70, and 80 ms). Alternatively, the LI-ER group did not differ from either the LI-E group or the age-matched control group. These findings clearly suggest subgroup differences in the identification and TOJ abilities in children with language impairments. However, articulation abilities of children who participated in the TOJ portion of the study were not reported, so it is not clear from these findings what the relationship is between TOJ abilities and speech and/or language impairments in this group of children.

Yet another difficulty that children with SLI have in phoneme identification tasks is the discrimination of target sounds embedded in a phonetic context. Leonard et al. (1992) and Sussman (2001) reported that children with SLI easily distinguished spectrally dissimilar synthetic vowels in isolation but failed to distinguish those same vowels in a phonetic context ([dab-i-bal]–[dab-u-bal] and [bib]–[bæb], respectively). Recently, however, Evans, Viele, Kass, and Tang (2002) used both naturally spoken and synthetic tokens to examine discrimination of target sounds in a phonetic context by children with SLI. They compared natural and synthetic versions of tokens originally used by Leonard et al. (1992)—[i]–[u] in isolation, [i]–[u] in a [dab-i-ba]–[dab-u-ba] context, and [s]–[ʃ] in a [das]–[daʃ] context. Children with SLI successfully discriminated both synthetic and natural tokens of steady-state vowels, but only discriminated naturally produced vowels in the [dab-V-ba] context. Further, they could not discriminate either natural or synthetic versions of fricatives [s]–[ʃ] in the [daC] context. Using natural speech only, McReynolds (1966) also found that children with LI could identify consonants in isolation, but not in a phonetic context. The conclusion drawn from these studies was that children with SLI have difficulty processing brief or rapidly presented sounds, especially when they occur with other brief or rapidly presented sounds. Further, children with SLI have even more difficulty discriminating synthetic versions of these speech contrasts.

Finally, researchers have used categorical perception tasks to evaluate speech perception deficits in children with SLI. In these tasks, researchers have typically used synthesis or editing to create series of stimuli that differ incrementally in one or more acoustic dimensions. When listeners are asked to identify tokens from such a series, they readily partition the series into two (or more) phonemic classes. Because monotonically varying tokens are perceived discontinuously, perception is said to be categorical. The categorical perception task includes components from other perceptual tasks—phoneme identification (Evans et al., 2002; Leonard et al., 1992; McReynolds, 1966; Stark & Heinz, 1996a, 1996b; Sussman, 2001) and discrimination (Elliott & Hammer, 1988; Elliott et al., 1989), thereby requiring an intact auditory/perceptual system. At the same time, it is the most basic linguistic task, owing to its focus on the smallest units of language (phonemes), which serve as the building blocks for higher levels of language. As outlined by Wood (1976), three features define categorical perception: (a) a sharp labeling (identification) function, (b) discontinuous discrimination performance (near perfect across identification boundary and

near chance to either side), and (c) the ability to predict discrimination performance on the basis of labeling data.

Researchers have suggested that children with SLI perceive speech less categorically than children developing language typically (e.g., Sussman, 1993; Thibodeau & Sussman, 1979). Thibodeau and Sussman (1979) examined categorical perception of a synthetic [ba]–[da] series in children with language disorders (LD) and/or articulation (A/LD or AD) disorders and controls with NL. For all four groups, there was no difference in crossover points of identification functions. They next examined identification patterns for only unambiguous endpoint tokens, essentially the phoneme identification task described above. For children with only LD or AD, Thibodeau and Sussman found similar performance on unambiguous endpoint tokens as an age-matched control group (93%–100%). However, the group with language and articulation disorders (A/LD) was less accurate on endpoint tokens (85%–93% correct). Also, children with only LD had shallower identification functions than the control group. When identification was used to predict discrimination, they found similar correlations between observed and predicted values across the full series of stimuli, but children with LD showed a greater discrepancy between observed and predicted peak discrimination values near the identification crossover. Sussman (1993) also used a synthetic [ba]–[da] series and found shallower identification functions, which she hypothesized to be indicative of greater overlap in phonemic representations for children with both language and severe speech disorders. In this study, Sussman also found that these children were less consistent at labeling unambiguous [ba]–[da] endpoint stimuli. Unlike the previous study, however, no difference in discrimination abilities was found.

Joanisse, Manis, Keating, and Seidenberg (2000) compared identification (without discrimination) of a synthetic “spy”–“sky” [spaI–skaI] series and a naturally spoken “dug”–“tug” [dʌg–tʌg] series in a group of children with dyslexia and two groups of normal readers: age matched and reading level matched. All children were initially identified by their teachers as either normally achieving or poor readers. In addition to reading assessment measures, all children received the Word Structures subtest of the Clinical Evaluation of Language Fundamentals—Third Edition (CELF–III; Semel, Wiig, & Secord, 1995) and the Vocabulary subtest of the Wechsler Intelligence Scale for Children—Third Edition (WISC–III; Wechsler, 1992) to assess semantic and lexical difficulties. In addition to primary reading analyses, Joanisse et al. analyzed subgroups of children with dyslexia. Children with dyslexia were separated into subgroups based on whether they had concomitant LI as measured by the Word Structures subtest of the CELF–III and the Vocabulary subtest of the WISC–III. Children with dyslexia and LI were less consistent labeling unambiguous endpoint stimuli and had shallower identification functions for both speech contrasts. Although the children in this particular group did not have complete expressive and receptive language measures, if these children are assumed to have SLI, these findings replicated prior categorical perception results in children with SLI. The findings from these three studies have led researchers to speculate that children with SLI are less categorical in their speech perception, or that they have more overlap between internal representations of adjacent phonetic categories (e.g., Joanisse & Seidenberg, 1998).

Although the evidence suggests that children with SLI experience deficits in basic speech perception abilities, there are reasons to suspect that these findings underestimate children's true perceptual abilities. Perhaps most obviously, researchers have found evidence of categorical perception of speech in populations without language. Using a high-amplitude sucking paradigm, Eimas, Siqueland, Jusczyk, and Vigorito (1971) have shown that 1-month-old, prelinguistic infants discriminate minimal phonetic pairs. They respond to changes in phoneme identity, but fail to respond to changes within a phonemic class, that is, they exhibit discontinuous discrimination. Kuhl and Miller (1975, 1978; Kuhl, 1981) have demonstrated that chinchillas also show evidence of categorical perception. They "label" and discriminate voiced ([b],[d],[g]) from voiceless ([p],[t],[k]) stop consonants in a fashion remarkably like that found for human listeners with the same stimuli, fulfilling all of the above requirements for categorical perception. Because infants and chinchillas show evidence of categorical perception, it seems unlikely that children with SLI should be less capable than infants or chinchillas.

There are three reasons to suspect that their apparent perceptual deficits may be confounded with other factors. First, methods used to evaluate speech perception abilities contain a significant memory component. Because children with SLI have significant difficulties with auditory memory (Gathercole & Baddeley, 1990; Kirchner & Klatzky, 1985), memory-intensive perceptual tasks might not reflect true perceptual abilities. For example, the TOJ task used by Tallal and Piercy (1973, 1974, 1975) required that children identify tokens and remember the order in which they occurred. Errors could result from deficient perception or from deficient ordering of stimuli. Similarly, the oddity method that Thibodeau and Sussman (1979) used to examine discrimination required listeners to judge which of three sounds was unlike the other two. This required the listener to remember and compare three different stimuli. Compare this with the change/no-change method used by Sussman (1993). In this task, listeners heard two identical syllables followed by another two identical syllables. In some cases, pairs were different (change), while in other cases pairs were identical (no-change). For this task, listeners did not have to remember individual tokens. Instead, they simply had to detect a change. Using the more memory-intensive oddity method, Thibodeau and Sussman found that children with SLI were less able to discriminate tokens drawn from different categories. However, with the less memory-loaded change/no-change method, Sussman found that children with SLI exhibited a similar pattern of discrimination as that of a group of age-matched control children.

The second potential confound has to do with the use of synthesized test items. In naturally occurring speech, virtually every linguistically relevant (phonemic) contrast between speech sounds is specified by more than one acoustic property, and many studies have demonstrated that adult listeners are sensitive to multiple acoustic properties when making phonetic judgments (see, e.g., Repp, 1982). For example, despite the fact that the voicing distinction in syllable-initial stops is frequently referred to simply as a difference in voice onset time (VOT), this articulatory description covers a broad array of acoustic differences between [+voice] and [-voice] stops. In production of the voicing distinction, the seemingly straightforward timing relation between constriction release and vocal-fold vibration actually gives rise to a broad array of acoustic attributes. For English [+voice] stops, periodic energy resulting from vocal-fold vibration either precedes or is nearly coincidental with the

burst of noise occurring at release (sometimes absent for labials), whereas for [–voice] stops, onset of periodicity typically follows release by about 40 to 100 ms (Lisker & Abramson, 1964). During the delay between release and voice onset, there is little or no energy in the frequency region of the first formant (F1), and there is aperiodic energy (frication and aspiration) at higher frequencies. The interval between articulatory release and voice onset, along with the cluster of acoustic attributes consequent to this articulatory maneuver, are often described jointly (conflated) as the dimension of VOT. When investigators “unpack” individual acoustic attributes in experiments using synthesized syllables, it is revealed that, in addition to duration of the interval between burst and onset of periodic energy, amplitude of aspiration energy (Repp, 1979), amplitude onset characteristics following the burst (Darwin & Pearson, 1982), duration of the F1 transition (Lisker, Liberman, Erickson, & Dechovitz, 1977; Stevens & Klatt, 1974; Summerfield & Haggard, 1977), and onset frequency of F1 (Kluender, 1991; Lisker, 1975, Summerfield & Haggard, 1977) all contribute to perception of voicing.

Although phonetic contrasts in natural speech are specified by multiple acoustic cues, many or most of these may be absent in synthetic speech. Adult listeners show better perception and comprehension of natural speech tokens as compared to synthetic speech tokens (Luce, Feustel, & Pisoni, 1983; Nusbaum & Pisoni, 1985). Further, Luce et al. (1983) have reported that recall for naturally spoken word lists was superior to that for synthesized word lists. Because children with SLI are known to have memory difficulties, use of synthetic speech stimuli in tests of perception necessarily conflates measures of both memory and auditory perception. Using synthetic speech, Leonard et al. (1992) found that children with SLI failed to discriminate vowels embedded in a phonetic context, whereas Evans et al. (2002) found that children with SLI could discriminate these very same vowels in the same context when they were naturally produced. Thus, there is evidence that children with SLI might have more difficulty discriminating synthetic speech. The findings from Joanisse et al. (2000) that children with dyslexia and LI are less categorical when identifying a synthetic “spy”–“sky” series are consistent with this difficulty. What is interesting, however, is that Joanisse et al. observed that this group of children with dyslexia and LI was also less categorical on natural tokens of a “dug”–“tug” series. Though these words are familiar to adults, they are infrequent verb forms with low concreteness and imageability, suggesting a third potential confound related to the abstract nature of test items.

Studies thus far have examined the perception abilities of children with SLI by using abstract syllables rather than real words. Recently, Metsala (1999) presented evidence that typically developing children’s phonological representations of familiar words are more robust than those of less familiar words. It therefore follows that familiar words will be even more robustly represented than abstract syllables (e.g., “ba”–“da”). Bishop (2000) and Evans (2002) have suggested that children with SLI have more fragile underlying phonological representations. Thus, it may be that processing abstract test stimuli may be even more problematic for children with SLI as compared with their peers.

Taken together, extant findings of relatively poor performance by children with SLI in auditory perception tasks could be attributed to cumulative effects of synthetically produced speech contrasts in tasks with high memory demands and abstract, unfamiliar test items. The

current study examined categorical perception by a group of children with SLI and a chronological age matched control group. To ensure that any potential differences in perception are attributed to LI and not to articulation deficits, only children with clear articulation were included. The experimental task was designed to minimize memory demands, processing demands (associated with synthetic speech), and representational demands (associated with abstract syllables). In this way, a clearer picture of these children's perceptual abilities could emerge. If children with SLI have an underlying auditory deficit, either general or specific to speech, then using a task with low memory demands and naturally spoken, concrete test stimuli should have no effect. If, on the other hand, their perceptual abilities are intact, but their performance is confounded by memory, processing, or representational demands, then alleviating these problems should result in patterns of performance similar to those for typically developing children.

Method

Participants

Participants for this study included 20 monolingual English-speaking children with SLI (9 females, 11 males; mean age = 9;3 [years;months]; age range = 7;3–11;5) and 20 typically developing children matched for chronological age (14 females, 6 males; mean age = 8;7; age range = 6;11–10;0). The age difference between groups was not significant, $t(38) = -1.70$, $p = .10$, $\omega^2 = .045$, power = .45. Most children were drawn from a larger sample of children in local schools. Some additional children were referred by previous participants. The children with SLI met exclusion criteria (Leonard, 1998), having no frank neurological impairments, no evidence of oral–motor disabilities, normal hearing sensitivity, and no social or emotional difficulties (based on parent report). Nonverbal IQs were at or above 85 (1 *SD* below the mean or higher) as measured by the Leiter International Performance Scale—Revised (Leiter–R; Roid & Miller, 1997) or the Columbia Mental Maturity Scale (Burgemeister, Blum, & Lorge, 1972). In addition, to control for possible confounding effects of articulation impairments, only children without articulation deficits were included. Speech intelligibility, as measured during spontaneous speech, was at or above 98% for all children. All children also had normal range hearing sensitivity on the day of testing as indexed by audiometric pure-tone screening at 25 dB for 500 Hz tones and at 20 dB for 1000, 2000, and 4000 Hz tones. One typically developing child failed the hearing screening and was not tested that day. She passed the hearing screening on her next visit and participated in the full experimental battery.

Language assessment measures included (a) the CELF–R (Semel et al., 1989), (b) the Nonword Repetition Task (NWR; Dollaghan & Campbell, 1998), and (c) the Competing Language Processing Task (CLPT; Gaulin & Campbell, 1994). Children with SLI received the full expressive and receptive language batteries of the CELF–R, and composite expressive (ELS) and receptive (RLS) language scores were calculated. Typically developing children received the full expressive language battery of the CELF–R, and their receptive language was screened with the Oral Directions subtest of the receptive language battery of the CELF–R.

The group of children with SLI included 8 children with only expressive language impairments (E–SLI) and 12 children with both expressive and receptive language impairments (ER–SLI). The language criteria for E–SLI were ELS at least 1 *SD* below the mean (<85) and RLS greater than 1 *SD* below the mean (>85). Criteria for ER–SLI were ELS and RLS at least 1 *SD* below the mean (<85). One child received an ELS of 86 but an RLS of 76. Given the standard error of measurement, ± 5 points, and her low RLS, she was identified as having ER–SLI. Language criteria for the age-matched group were ELS above 85 and standard score on the Oral Directions subtest at or above 8. Three typically developing children received low standard scores (<7) on the Oral Directions subtest and therefore received the full receptive language battery. For all 3 of these children, scores on the full receptive language battery fell within the normal range.

Group summary statistics are provided in Table 1. Children with SLI scored significantly lower than age-matched children on all diagnostic measures: CELF–R ELS, $t(38) = 7.79$, $p < .05$, $\omega^2 = .599$, power = .99; CELF–R Oral Directions subtest, $t(38) = 3.41$, $p < .05$, $\omega^2 = .21$, power = .99; NWR, $t(37) = 2.69$, $p < .05$, $\omega^2 = .134$, power = .98; and CLPT, $t(38) = 4.85$, $p < .05$, $\omega^2 = .36$, power = .99. Individual scores for the children with SLI are provided in the Appendix.

Stimuli

Test items were the words “bowl” and “pole.” These words were chosen because they contain the [b]–[p] voicing contrast on which children with SLI repeatedly have been tested. Further, both words have very similar, high (adult) ratings of word familiarity, concreteness, imageability, meaningfulness (Coltheart, 1981), and word frequency (Kuera & Francis, 1967). Because both words are real, familiar, concrete, imageable, and meaningful, children have no a priori reason to favor one choice over the other. The words were produced several times by an adult female with an upper Midwestern accent who was asked to speak the words in pairs as similar to one another as possible. That way, any potential pitch, duration, or amplitude differences were minimized. The speaker produced the words in a soundproof chamber, and they were recorded directly into a Windows-based waveform analysis program. They were digitized at a 44.1-kHz sampling rate with 16-bit resolution. One pair of tokens with very similar pitch, duration, and amplitude was chosen for further processing.

The pair of tokens was used to construct a six-member “bowl”–“pole” series in which the perceptual change from [b] to [p] was accomplished by manipulating the duration of aperiodic energy (aspiration) in the word-initial stop consonant. As noted earlier, VOT is defined articulatorily as the time between the release of oral closure and the onset of vocal fold vibration and is measured acoustically as the time between the abrupt increase in energy at consonantal release and the onset of periodicity. These durations were 0 ms for “bowl” and 52 ms for “pole.” As is typical of bilabial stop consonants, the noise burst at release was weak for both tokens. The naturally spoken token of “bowl” was the first endpoint stimulus. Intermediate steps in the series were created by deleting the burst and successively larger acoustic segments of periodic energy from “bowl” and replacing these acoustic segments with the burst and equally long acoustic segments of aperiodic energy taken from “pole.” Each step represented two pitch pulses of voicing, or approximately 10 ms, being replaced

by an equal duration of aperiodic energy from “pole.” A 10-ms step size was chosen to provide a manageable number of stimuli for children while maintaining sufficient temporal resolution to examine potential differences in identification functions. The 50-ms token served as the “pole” endpoint of this series. All edits were made at the end of a pitch pulse at a zero crossing. Thus, there was no audible indication (e.g., presence of a click) that stimuli had been created by digitally splicing two different words. Naïve adult listeners consistently perceived the stimuli to be unedited tokens of natural speech. The total duration of each stimulus was 391 ms.

Stimuli were transferred to compact discs for presentation. Two types of stimulus sequences were created—those for the identification portion and those for the discrimination portion. For the identification portion, each stimulus was presented twice on a single trial separated by a 1-s ISI. Two presentations of each stimulus were presented within a single trial to mitigate memory demands. For the discrimination portion, each token was paired with itself and with tokens two or more steps away in the series. For example, the third token in the series (20-ms VOT) was paired with the first, third, fifth, and sixth tokens (0-, 20-, 40-, and 50-ms VOTs, respectively). Test items were pairs of tokens differing in VOT by 20 ms, or two steps in the series (0–20, 10–30, 20–40, and 30–50). This 20-ms difference was chosen to allow examination of both within- and across-category discrimination. Pairs consisting of identical tokens served as catch trials, while pairs consisting of tokens with more than a 20-ms difference served as filler trials. For the discrimination portion of the task, memory demands were limited in two ways. First, pairs of tokens were separated by a very short (100-ms) ISI, which serves to minimize memory requirements (Fujisaki & Kawashima, 1971; Pisoni, 1973). Also, as in the identification portion, stimulus pairs were presented twice in a single trial separated by a 2-s ISI. As in Sussman’s (1993) task, children could respond based on whether they heard any change across stimuli. That way, memory load associated with storing and comparing pairs of items was presumably minimized. Each pair of tokens (in both orders) was presented twice in a fixed random order. That is, each test trial was presented two times in two different orders, for a total of four presentations.

Procedure

Children participated in the identification and discrimination tasks as a part of a larger experimental test battery. For all children, this was the second perceptual task, occurring after a break, approximately 20 min into the session. Listeners were tested individually in a large, soundproof chamber (Acoustic Systems). Test items were presented over a single speaker (Realistic Minimus 7) at 75 dB SPL. Frequency response (100–10000 Hz.) was measured earlier to be acceptably flat, and presentation level was calibrated at the beginning of each session. The speaker was positioned approximately 2 ft in front of the listener. For the identification task, children were told that they would be hearing a woman saying either “bowl” or “pole.” Their job was to listen and identify each word by pointing to a picture (i.e., a two-alternative forced-choice task). Colored pictures of bowls and poles were contained in a notebook, with the item positions and positions of correct answers randomized (right or left). The experimenter provided two practice trials in which he said each word aloud and prompted the listener to point to the appropriate picture. None of the children had any difficulty with the identification portion of the task. Once testing began,

listeners heard two presentations of each token, and the experimenter recorded their responses. Over 60 trials, children listened to 10 presentations of each stimulus. After the identification task, all children participated in the discrimination task. Listeners were told that they would hear the same words, and their job was to determine if the two words were the same or different (i.e., an AX discrimination task). Again, the experimenter produced one of each stimulus type as practice trials to make sure that children understood the task. Children listened to each pair of tokens and were asked to judge if they were the same or different. Children responded verbally, and the experimenter recorded their responses. All children heard 48 pairs of tokens in the same fixed random order, for a total of 4 presentations of each test trial, 2 presentations of each catch trial, and 20 filler trials.

Results

Identification functions for the “bowl”–“pole” series were obtained by calculating the percentage of “pole” responses (out of 10) for each stimulus along the six-step series. The results are shown in Figure 1. Tokens with lower VOT values were consistently identified as “bowl,” while those with higher VOTs were identified as “pole.” For both groups, there was a sharp shift in identification. Discrimination functions for both groups are provided in Figure 2. For both groups of children, discrimination is good for tokens drawn from across the identification crossover, but poor for tokens likely to be identified the same. To examine potential perceptual deficits in the group of children with SLI, group performance was compared to the typically developing children’s group performance. Potential group differences in identification were examined first by comparing the number of “pole” responses as a function of VOT and, second, by comparing the results of probit analyses for both groups. Probit analysis fits a cumulative normal curve to probability estimates as a function of stimulus level by the method of least squares (Finney, 1971), estimating the mean (identification crossover) and standard deviation for each distribution. Discrimination was examined by comparing the number of “different” judgments for the two groups as a function of stimulus pair. Finally, group identification results were used to predict discrimination functions, and these predicted functions were compared to obtained discrimination functions.

Identification

For the “bowl”–“pole” series, typically developing children made an average of 28.1 “pole” responses, while the children with SLI made an average of 28.9 “pole” responses. The percentage of “pole” responses was entered into a 2 (group) $\times$ 6 (VOT) mixed-design analysis of variance (ANOVA). There were no group differences in the overall number of “pole” responses, $F(1, 38) = 0.43$, $p = .52$, $\omega^2 < 0$.¹ There was a significant effect of stimulus level, $F(5, 190) = 595.80$, $p < .05$, $\omega^2 = .937$, power = .99, indicating that tokens with lower VOT values were identified as “bowl” and those with higher values as “pole.”

¹Effect sizes (ω^2) and power were calculated for all statistical results. *Effect size is a function of test statistic and sample size, and can be interpreted as the amount of total population variance accounted for by variance due to group differences.* Power, or the probability of obtaining a significant test statistic if a significant difference truly exists, is then calculated as a function of effect size, sample size, and alpha level (.05). Conditions that show no significant group differences therefore have small effect sizes and, consequently, little power. Based on the way these are calculated, F values (or t values) less than 1 result in effect sizes with negative values, and power cannot be calculated.

The Group $\times$ Stimulus Level interaction approached but did not reach significance, $F(5, 190) = 2.02$, $p = .08$, $\omega^2 = .025$, power = .35, indicating no significant group difference in overall identification functions. Although this interaction term did not reach significance, point-by-point comparisons were conducted to determine any group differences in identification patterns. These comparisons revealed a single significant difference—children with SLI were more likely to label the 20-ms VOT token as “pole” 17.5% of the time, as compared to the CA-matched children’s 5.0% “pole” responses, $t(38) = -2.12$, $p < .05$, $\omega^2 = .08$, power = .42. No other pairs were statistically different: VOT₀₀, $t(38) = 0$, $p = 1$, $\omega^2 < 0$; VOT₁₀, $t(38) = 0$, $p = 1$, $\omega^2 < 0$; VOT₃₀, $t(38) = 0.43$, $p = .67$, $\omega^2 < 0$; VOT₄₀, $t(38) = 1.24$, $p = .22$, $\omega^2 = .01$, power = .20; VOT₅₀, $t(38) = -0.59$, $p = .56$, $\omega^2 < 0$.

Next, accuracy on only endpoint stimuli was examined. Previous work has shown that children with SLI are less accurate on unambiguous endpoints (Joanisse et al., 2000; Sussman, 1993). Other researchers have used accuracy on unambiguous endpoints as a measure of attention (e.g., Lotto & Kluender, 1998; Nitttrouer & Studdert-Kennedy, 1987). Typically developing children had a mean accuracy of 99.5%, while children with SLI had a slightly higher mean accuracy of 99.8%. This 0.3% difference was not significant, $t(38) = -0.59$, $p = .56$, $\omega^2 < 0$.

Identification data for each listener were entered into probit analyses. As explained above, probit analysis fits a cumulative normal curve, providing a mean (50% point) and standard deviation (Finney, 1971). The mean 50% crossover point for typically developing children was at 27.8 ms, while that for children with SLI was 26.0 ms, a nonsignificant difference, $t(38) = 1.48$, $p = .15$, $\omega^2 = .029$, power = .35. The slope of the identification function, obtained by taking the reciprocal of the standard deviation, serves as an index of consistency (see Nitttrouer & Studdert-Kennedy, 1987). The mean slope for typically developing children was 0.68, while that for children with SLI was 0.49. Although slopes were higher for typically developing children, this difference was not significant, $t(38) = 1.48$, $p = .15$, $\omega^2 = .029$, power = .35. Standard deviation values sometimes have been used to infer width of identification boundaries. Zlatin and Koenigsnecht (1975) identified boundary width (somewhat arbitrarily) as the linear distance between the 25th and 75th percentiles as determined by the mean and standard deviation obtained from probit analysis. The mean boundary width, defined by standard deviation, was 3.8 ms for typically developing children and 5.5 ms for children with SLI, also not significant, $t(38) = 1.31$, $p = .20$, $\omega^2 = .017$, power = .30. These results from probit analyses show that the two groups did not differ significantly in their identification functions. For both groups of children, there was a sharp boundary between categories, fulfilling the first requirement for categorical perception.

Discrimination

To compare discrimination functions, the percentage of “different” responses was entered into a 2 (group) $\times$ 4 (stimulus pairs) within-subjects ANOVA. As explained above, stimulus pairs consisted of tokens differing by 20 ms VOT. The four stimulus pairs were 00–20, 10–30, 20–40, and 30–50. The two groups did not differ in percentage of “different” responses, $F(1, 38) = 1.47$, $p = .23$, $\omega^2 = .012$, power = .30. There was a significant effect of stimulus pair, $F(3, 114) = 66.42$, $p < .05$, $\omega^2 = .71$, power = .99, indicating superior discrimination for

cross-boundary pairs. The Group $\times$ Stimulus Pair interaction was also significant, $F(3, 114) = 5.33, p < .05, \omega^2 = .14$, power = .81, indicating that discrimination functions for the two groups were different. A point-by-point comparison revealed a significant difference for one pair of stimuli identified equivalently and differences for cross-boundary pairs—00–20: $t(38) = -3.25, p < .05, \omega^2 = .192$, power = .99; 10–30: $t(38) = 1.78, p = .08, \omega^2 = .051$, power = .51; 20–40: $t(38) = 2.17, p < .05, \omega^2 = .085$, power = .83; and 30–50: $t(38) = 0.96, p = 0.35, \omega^2 < 0$. Children with SLI discriminated both cross-boundary pairs at better than chance levels—10–30: $t(19) = 2.18, p < .05, \omega^2 = .372$, power = .815; 20–40: $t(19) = 2.84, p < .05, \omega^2 = .15$, power = .989. Although the children with SLI exhibited lower peak discrimination values, both groups exhibited clear, distinct discontinuous discrimination performance, fulfilling the second requirement for categorical perception.

One possible explanation for group discrimination differences is that they might have resulted from differences in attention between the two groups. To check whether the two groups were attending equally to the task, discrimination on identical pairs was compared. Typically developing children gave “different” responses to identical tokens 7.5% of the time, while children with SLI did so 9.2% of the time. This difference was not significant, $t(38) = 0.48, p = .63, \omega^2 < 0$, indicating that both groups of children were attending to the task with similar diligence.

Finally, group identification functions were used to predict discrimination functions using simple probabilities. For example, if two tokens were both perceived as “pole” 10% of the time, then they should be perceived as “different” 18% of the time (Token 1 “pole” probability multiplied by Token 2 “bowl” probability [$.10 \times .90 = .09$] plus Token 1 “bowl” probability multiplied by Token 2 “pole” probability [$.90 \times .10 = .09$]) and “same” 82% of the time (Token 1 “pole” probability multiplied by Token 2 “pole” probability [$.10 \times .10 = .01$] plus Token 1 “bowl” probability multiplied by Token 2 “bowl” probability [$.90 \times .90 = .81$]). The correlation between predicted and obtained discrimination values was then calculated for both groups (for typically developing children, $r = .995$; for children with SLI, $r = .926$). That is, for both groups of children, identification predicted discrimination very well, fulfilling the third requirement for categorical perception.

Discussion

The purpose of the current study was to examine the degree to which deficits in SLI are dependent on or extend to lower level processes such as auditory and phonetic perception. To address potential confounds in prior studies, categorical perception of speech by children with SLI was investigated in a task that required little memory and used very high quality edited natural tokens of familiar words. A stringent three-level criterion was used to assess categorical perception, defined by (a) a sharp identification function, (b) discontinuous discrimination performance, and (c) the ability to predict discrimination from identification. The children with SLI and the age-matched control children fulfilled all three of these requirements despite differences in language and verbal and phonological working memory abilities. Identification functions for children with SLI and for typically developing children were virtually indistinguishable. In keeping with previous studies, children with LI consistently placed crossover points at the same locations as control groups. In earlier

studies, however, children with SLI consistently exhibited shallower slopes between categories (Joanisse et al., 2000; Sussman, 1993; Thibodeau & Sussman, 1979) and less consistent labeling for unambiguous endpoint tokens (Sussman, 1993; Thibodeau & Sussman, 1979). Children with SLI in the present study did not exhibit these differences. In the current study, peak discrimination was somewhat lower for children with SLI, but—consistent with categorical perception—discrimination was markedly discontinuous across the series. For both groups of children, tokens that received different labels were discriminated significantly better than chance, whereas tokens sharing the same label were not discriminated. When identification was used to predict discrimination, correlations between observed and predicted values were comparable for both groups of children. When natural renditions of real words were used in a task that minimized memory load, children with SLI exhibited the same hallmarks of categorical perception found for typically developing children, despite substantial differences in language measures.

When considered alone, children with SLI fulfilled all of the requirements for categorical perception. Relative to unimpaired, age-matched control children, however, the group of children with SLI exhibited poorer discrimination, as evidenced by the fact that they were less likely to report differences between stimuli that they had previously labeled differently. A reasonable interpretation of these results is that children with SLI perceive speech less categorically than children with no history of LI. Although these children could successfully label high-quality versions of naturally spoken real words comparably to children with no history of LI, they were less likely to report that two tokens drawn from either side of the labeling boundary were different. This replicates previous findings that children with SLI require greater acoustic difference to discriminate speech tokens (Elliott & Hammer, 1988; Elliott et al., 1989).

Such an interpretation is consistent with the present results in some ways; however, the data also support an alternative, more conservative conclusion. The profound language deficits exhibited by children with SLI may not be a consequence of such subtle, if existing, perceptual deficits. Children with SLI in the current study exhibited all of the hallmarks of categorical perception. Further, children with SLI did not differ from the control group in their identification functions, and the ability to predict discrimination from identification was comparable for both groups. Only the measure of peak discrimination differed significantly between the two groups. Although this group difference in discrimination is consistent with a perceptual deficit, it also is consistent with a deficit in memory, processing, or representation, manifested as increased susceptibility to task demands. To begin critical evaluations of these interpretations, the discussion will turn to categorical perception more generally, and to why children with SLI might be expected to perceive categorically.

Begin by considering what a deficit in categorical perception would entail. In the extreme case, perception would be continuous or nearly so. Less severe deficits would include relatively shallow identification functions suggesting an extended region of ambiguity. Noncategorical or continuous identification performance should correspond to relatively flat discrimination performance. Flatter patterns of discrimination across the range of stimuli have been taken to imply less precise or “noisy” response patterns, as reported by Thibodeau and Sussman (1979) for children with LI. Alternatively, relatively flat discrimination

performance could result from two different sources. First, listeners could focus on acoustic differences and ignore category labels when discriminating speech tokens. Evidence supporting this would be both within- and across-boundary pairs being discriminated at better than chance levels. Along this line, Serniclaes, Sprenger-Charolles, Carré, and Demonet (2001) reported that children with dyslexia were more likely than average readers to discriminate within-boundary pairs. The second possibility is that listeners could require large acoustic differences to differentiate any pair of tokens, as reported for children with language-learning problems by Elliott and colleagues (Elliott & Hammer, 1988; Elliott et al., 1989). In this second case, all pairs of modestly different acoustic tokens would be discriminated at near-chance levels. Importantly, for all of these explanations, listeners with impaired categorical perception should show deficits in both identification and discrimination. Finally, such a group should show a discrepancy between obtained and predicted discrimination functions, over and above reduced discrimination predicted by shallower identification functions.

In practice, a clinical group's identification and discrimination performance is compared to that of a control group. Any statistically significant differences between groups are interpreted as differences in the degree of categorical perception. A number of studies have found some difference or another in discrimination performance between a clinical group and a control group and have concluded that the clinical group perceives speech tokens less categorically (e.g., dyslexia: Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Serniclaes et al., 2001; Werker & Tees, 1987; SLI: Thibodeau & Sussman, 1979). However, for those studies in which the discrimination task was paired with an identification task, shallower identification functions in clinical groups were found compared to control groups (Godfrey et al., 1981; Thibodeau & Sussman, 1979; Werker & Tees, 1987). That is, poorer discrimination performance always accompanied poorer identification performance. In contrast to this pattern, Sussman (1993) found significant group differences in identification functions between children with SLI and age-matched controls, but no differences in discrimination performance. That is, an identification deficit can occur alone, without a concomitant discrimination deficit, but the opposite pattern has not previously been demonstrated. Why, then, might discrimination performance have been poorer in the current study?

While lower peak discrimination values might indicate a deficit in perception, alternatively, they may actually result from different levels of susceptibility to task demands. For the children with SLI, weaker performance in the discrimination task relative to that of control children, could, in part, be due to the ISI (100 ms) chosen in an effort to alleviate memory demands. Children with SLI have difficulty perceiving spectrally similar sounds in a phonetic context presented in rapid succession (Evans et al., 2002; Leonard et al., 1992; McReynolds, 1966; Stark & Heinz, 1996b; Sussman, 2001; Tallal & Piercy, 1974, 1975). For the present case, children with SLI may have benefited from decreased memory load with 100-ms ISI but suffered from the relatively brief ISI of rapid presentation. As described above, when a longer ISI (500 ms) is used, children with SLI discriminate speech tokens well, with no group differences between them and age-matched control children (Sussman, 1993). One may conclude from the present study that, when task demands are greatly

simplified, speech token identification by children with SLI does not differ from that of age-matched controls. Sussman (1993) provided parallel evidence for discrimination.

Based on identification performance from this study, and on discrimination performance from the Sussman (1993) study, children with SLI appear to perceive speech categorically when task demands are suitably simplified. This replicates previous work showing that children with SLI are extremely vulnerable to external task demands when compared to typically developing children (e.g., Evans, 2002). Previous work has shown that performance suffers if they must respond to synthetic versions of abstract syllables in tasks with high memory demands (Elliott & Hammer, 1988; Elliott et al., 1989; Evans et al., 2002; Joannis et al., 2000; Leonard et al., 1992; McReynolds, 1966; Stark & Heinz, 1996a, 1996b; Sussman, 1993, 2001; Tallal & Piercy, 1974, 1975; Tallal & Stark, 1981; Tallal et al., 1981; Thibodeau & Sussman, 1979). Because perception by children with SLI appears relatively unimpaired when memory, processing, and representational demands are minimized, auditory or speech perception deficits seem an unlikely underlying cause of LI. Instead, the present results may implicate deficits in memory, processing, or representation as the underlying source of impairment in this group of children.

Of particular interest here are representational deficits. Bishop (2000) and Evans (2002) have argued that an underlying deficit in linguistic representations can account for language outcomes in these children. According to this view, children with SLI have fragile underlying linguistic representations, and this has deleterious effects on memory and processing abilities. If underlying representations are not sufficiently robust to support memory or processing demands, then children will show performance breakdowns like those reported by Evans (2002). Bishop suggested that children with SLI can develop alternative processing strategies that could result in unimpaired levels of performance. Nevertheless, if alternative strategies provide the appearance of being unimpaired, such individuals may still perform poorly when their less robust representations are taxed by situations in which demands exceed their capabilities, or when they are presented with unfamiliar materials. Because these two processes, speech perception and representational facility, are difficult to thoroughly distinguish experimentally, a deficit in one can erroneously suggest a deficit in the other.

One potential confound in this current study is the seemingly low statistical power in cases of nonsignificant test statistics. Statistical power refers to a test statistic's ability to detect a true difference between groups, and is a function of sample size, alpha level, and effect size. In these cases with nonsignificant group differences, small effect sizes resulted in low statistical power. However, sample sizes in the current experiment were large enough to provide sufficient power to detect true group differences in diagnostic measures, such as those for the CELF-R ELS and Oral Directions subtest (Semel et al., 1989), the NWR task (Dollaghan & Campbell, 1998), and the CLPT (Gaulin & Campbell, 1994). In these cases, statistical power was very high, ranging from .98 to .99. Because statistical power was sufficiently high to detect group differences for several variables, low statistical power in the cases of non-significant test statistics appears less likely to have masked substantive differences between groups. In light of the present results, which reveal little difference between groups on categorical perception, it is worthwhile to consider why one might expect

individuals with SLI to exhibit categorical perception like that for the population more broadly.

First, categorical perception does not appear to be a signature characteristic restricted to speech and language processing. Categorical perception has been reported for musical intervals (Burns & Ward, 1974, 1978; Smith, Kemler Nelson, Grohskopf, & Appleton, 1994) and tempered triads (Locke & Kellar, 1973). Visually, humans categorically perceive human faces (Beale & Keil, 1995) and facial expressions (Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992; de Gelder, Teunisse & Benson, 1997), as well as cow faces morphed gradually to monkey faces (Campbell, Pascalis, Coleman, & Wallace, 1997). When human observers are trained with artificial categories, they gain acquired distinctiveness—increased perceptual sensitivity for items that are categorized differently (Goldstone, 1994). When monkeys are trained to respond differentially to clear examples of cats versus dogs (novel categories for monkeys), behavioral responses to stimuli along a morphed cat/dog series exhibit sharp crossovers at the series midpoint (Freedman, Riesenhuber, Poggio, & Miller, 2001). Perhaps the greatest proponent of specialized processes for perception of speech, Alvin Liberman (1996), did not view categorical perception as evidence for specialized processes. He even lamented that his own work was often interpreted as arguing that categorical perception was specific to speech, and he asserted that these attributions were overstated and never intended (Liberman, 1996, p. 201). Rather than being specific to speech, categorical perception is a general property of any perceptual system consequent to experience with regularities in the world.

Second, categorical perception appears to be an emergent property of almost any general learning system. Damper and Harnad (2000) reviewed evidence from human and animal listeners and from neural network models, and concluded that any number of generalized learning mechanisms can account for categorical perception. Models ranging from simple associative networks (e.g., Anderson, Silverstein, Ritz, & Jones, 1977) to back-propagation networks with no hidden units (e.g., Damper, Gunn, & Gore, 2000) exhibit categorical perception. Because categorical performance arises from a variety of simple learning algorithms, Damper and Harnad concluded that specialized processing is not necessary, and that “any general learning system operating on broadly neural principles ought to exhibit the essentials of [categorical perception]” (p. 862).

In light of the foregoing, it would be unexpected that individuals with SLI should display a deficit in categorical perception. Because categorical perception in children with SLI depends on task demands, further work needs to be done to determine how task demands cause perception to appear to be compromised. First, processing demands can be manipulated in tasks comparing categorical perception of natural versus synthetic speech. Second, representational demands can be manipulated in tasks comparing perception of real words versus abstract syllables (e.g., [ba]–[pa]). In both cases, children with SLI should experience difficulty due to increased processing demands associated with synthetic speech and abstract (unfamiliar) syllables. By exploring the nature of performance breakdown, a clearer picture of these children’s underlying linguistic representations should emerge.

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Appendix

Chronological age (years;months.days), composite expressive (ELS) and receptive (RLS) language scores on the CELF–R, percentage phonemes correct on the NWR, percentage final words recalled on the CLPT, and standard scores on nonverbal IQ measures for children with specific language impairments (SLI)

Participant	Age	ELS ^a	RLS ^a	NWR	CLPT ^c	Nonverbal IQ ^d
E-SLI1	10;10.24	78	101	95.83	29.6	107
E-SLI2	9;5.16	76	101	81.25	42.8	122
E-SLI3	9;0.25	76	91	77.08	19	110
E-SLI4	7;7.24	84	107	66.67	0	110
E-SLI5	10;6.13	78	89	71.88	38.1	115
E-SLI6	8;3.14	73	93	39.58	29	118
E-SLI7	10;2.8	84	103	73.96	35.7	106
E-SLI8	8;4.20	82	89	72.92	21	110
ER-SLI1	10;7.15	86	76	90.63	43.9	118
ER-SLI2	11;4.24	76	83	82.29	50	91
ER-SLI3	10;6.11	64	74	68.75	21.4	95
ER-SLI4	8;8.22	62	65	71.88	0	102
ER-SLI5	9;9.25	62	54	65.63	33.3	100

Participant	Age	ELS ^a	RLS ^a	NWR	CLPT ^c	Nonverbal IQ ^d
ER-SLI6	7;2.29	59	76	47.92	2.4	94
ER-SLI7	9;5.13	62	80	69.79	28.6	108
ER-SLI8	9;9.13	62	50	75	2.4	97
ER-SLI9	8;2.13	84	80	59.38	4.8	100
ER-SLI10	7;5.2	70	70		0	106
ER-SLI11	9;2.4	54	63	59.38	19	99
ER-SLI12	7;7.7	82	70	71.88	0	116

Note. The empty cell indicates that this child would not repeat any of the nonwords. NWR = Nonword Repetition Task; CLPT = Competing Language Processing Task.

^aClinical Evaluation of Language Fundamentals—Revised.

^bLeiter International Performance Scale—Revised or Columbia Mental Maturity Scale.

Figure 1. Identification functions for typically (TYP) developing children (solid line) and children with specific language impairments (SLI; dotted line). Percentage of “pole” responses is plotted as a function of voice onset time (VOT).

Figure 2. Discrimination functions for typically developing children (left plot) and children with SLI (right plot). Percentage of "different" responses is plotted as a function of stimulus pair. Obtained values are represented by solid lines, while values predicted from identification functions are represented by dotted lines.

Table 1

Group summary statistics for children with specific language impairments (SLI) and for typically developing children.

	Children with SLI	Typically developing children
Age	9;3 (1;3)	8;7 (1;0)
CELF-R ELS	72.7(10.0)	103.8 (11.4)
CELF-R RLS	80.8 (16.1)	–
NWR	70.6 (13.2)	80.9 (10.8)
CLPT	21.1 (16.9)	45.7 (15.2)

Note. Means (with standard deviations in parentheses) are presented for chronological age (years;months), composite expressive (ELS) and receptive (RLS) language scores on Clinical Evaluation of Language Fundamentals—Revised (CELF-R), percentage phonemes correct on the Nonword Repetition Task (NWR), and percentage final words recalled on the Competing Language Processing Task (CLPT) for children with SU.