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Speech perception and lexical effects in specific language impairment

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Abstract

Using an identification task, we examined lexical effects on the perception of vowel duration as a cue to final consonant voicing in 12 children with specific language impairment (SLI) and 13 age-matched (6;6–9;6) peers with typical language development (TLD). Naturally recorded CV/t/sets [word–word (WW), nonword–nonword (NN), word–nonword (WN) and nonword–word (NW)] were edited to create four 12-step continua. Both groups used duration as an identification cue but it was a weaker cue for children with SLI. For NN, WN and NW continua, children with SLI demonstrated certainty at shorter vowel durations than their TLD peers. Except for the WN continuum, children with SLI demonstrated category boundaries at shorter vowel durations. Both groups exhibited lexical effects, but they were stronger in the SLI group. Performance on the WW continuum indicated adequate perception of fine-grained duration differences. Strong lexical effects indicated reliance on familiar words in speech perception.

Keywords

specific language impairment; speech perception; lexicon; categorical perception

Introduction

Over 30 years of research has described speech perception deficits in children with specific language impairment (SLI), particularly on tasks that require identification of minimally distinct speech sounds (Elliot & Hammer, 1988; Evans, Viele, Kass, & Tang, 2002; Frumkin & Rapin, 1980; Hayiou-Thomas, Bishop, & Plunkett, 2004; Leonard, McGregor, & Allen, 1992; Stark & Heinz, 1996; Tallal & Stark, 1981; Tallal, Stark, Kallman, & Mellits, 1980). The precise nature of these deficits and their relationship to the more general language deficits observed in these children remains controversial (Bradlow et al., 1999; Coady, Evans, Mainela-Arnold, & Kluender, 2007; Rosen, 2003; Sussman, 1993). One view is that children with SLI have deficits in processing temporal features (e.g. duration) or deficits in temporal processing (i.e. processing acoustic features that are brief or rapidly changing).

Among the controversies regarding this view are whether speech perception deficits are limited to temporal aspects of perception, whether perceptual deficits differentiate children with SLI from their typically developing peers, and how these deficits impact other language domains.

Auditory perception and processing deficits

This auditory processing view has been supported by findings of impairments in perception of temporal features and features that are temporally brief or are presented rapidly (e.g. transition duration, vowel duration, stop gaps: Elliot & Hammer, 1988; Frumkin & Rapin, 1980; Stark & Heinz, 1996; Tallal, 1976; Tallal & Stark, 1981; Tallal et al., 1980). More recently, frequency discrimination deficits have also been identified (Hill, Hogben, & Bishop, 2005; McArthur & Bishop, 2004). However, deficits that occur in some adolescents with grammatical SLI are equally likely to occur in children without SLI (Rosen, Adlard, & van der Lely, 2009).

Auditory temporal processing deficits have been described in a variety of paired temporally distinct minimal speech sounds. Speech sound features that are brief, rapidly changing, delivered at a rapid rate, or have fine-grained duration differences were the basis for identification errors children with SLI made when responding to categorization or discrimination tasks (Elliot & Hammer, 1988; Tallal, Miller, & Fitch, 1993). Vowel pairs (e.g. /ε/-/I/), consonant–vowel syllable pairs (e.g. /ba/, /da/) and stressed and unstressed multi-syllable pairs (e.g. /dabida/, /dabuda/) differing by transition duration, inter-stimulus intervals, and vowel steady state durations have revealed temporal impairments (Bradlow et al., 1999; Burlingame, Sussman, Gillam, & Hay, 2005; Elliott & Hammer, 1988; Frumkin & Rapin, 1980; Leonard et al., 1992; McArthur & Bishop, 2004; Shafer, Ponton, Datta, Morr, & Schwartz, 2007; Stark & Heinz, 1996; Tallal & Stark, 1981; Tallal et al., 1980). The relative duration of neighboring segments and syllables (Leonard et al., 1992; Tallal & Piercy, 1975) also appears to affect identification accuracy. Despite this evidence, the characterization of these deficits as reflecting auditory temporal perceptual deficits rather than poor perceptual performance on difficult contrasts or deficits in higher level linguistic cognitive abilities remains controversial.

Vowel studies have reported adequate perception of long vowels (i.e. 250 ms) and poor perception of shorter vowels (Frumkin & Rapin, 1980; Tallal & Piercy, 1975; Tallal & Stark, 1981). Although the identification of short vowels (i.e. 40–100 ms) has yielded some variable results, two event-related potential and behavioral studies comparing vowels with durations of 50 and 250 ms (Shafer, Morr, Datta, Kurtzberg, & Schwartz, 2005), confirmed poor identification of phonetically similar vowels regardless of duration, but better discrimination of long vowels. For both vowel durations, there was evidence of a late negativity for the children with SLI, indicating discrimination of the speech sounds, but this discrimination occurred in a later time frame than for the children with typical language development (TLD). Similar to Bradlow et al. (1999), only 250 ms vowels yielded robust mismatch negativities in children with SLI (Datta, Shafer, Morr, Kurtzberg, & Schwartz, 2010) demonstrating more typical perception of longer vowels.

Cognitive-linguistic deficits

An alternative to the auditory perception deficit proposal is the view that speech perception deficits in children with SLI reflect, or at least interact with, cognitive–linguistic impairments (e.g. phonological aspects of representation such as category boundaries, lexical representation, attention; attentional control; or working memory). One proposal posited that poor perception of morphemes with low phonetic substance (e.g. brief, low intensity, etc.) requires greater allocation of processing resources to morphosyntactic learning for children with SLI (Leonard, 1989, 1998). Extensive cross-linguistic evidence generally supports this proposal. A more general proposal (Marinis, 2011) suggests that the core deficit in SLI lies in the integration of information at the interface of language components (Jakubowicz, 2003). Support for this notion comes from a finding that children at risk for SLI exhibit early auditory perceptual deficits with a specific effect on prosody. Later in development, these deficits can no longer be readily detected, but what remains are the varied deficits characteristic of SLI. Such proposals fall into a class of explanations that attribute perceptual deficits and their impact to cognitive–linguistic impairments (e.g. phonological aspects of representation such as category boundaries, lexical representation, attention; attentional control, or working memory).

The cognitive–linguistic view posits that the identification problem lies, not just in acoustic processing, but rather, in higher level categorization. According to this view, acoustic features are unimpaired. Instead, these children may have different phoneme boundaries or boundaries that are not as sharp because of greater uncertainty. This atypical category formation may be due to linguistic factors or language-related cognitive abilities affecting speech perception, lexical access or sentence processing such as memory (Marton & Schwartz, 2003), resource capacity (Leonard, 1989; Leonard et al., 1992) and attention (Shafer et al., 2007). According to this view, children with SLI suffer atypical and delayed language acquisition as a result of deficits in higher order linguistic processing. Proponents of both auditory and cognitive–linguistic views agree that poor phoneme recognition may cause children with SLI to be vulnerable to a host of language, learning and reading problems. But the direct links between speech perception and these abilities remain undetermined.

Vowel duration and final consonant voicing

One aspect of English that depends directly on children's perception of vowel duration is the voicing of final consonants. When the voice bar is removed from final stop consonants, short vowels cue voiceless consonants (e.g. /t/ in *feet*), and long vowels cue voiced consonants (e.g. /d/ in *feed*). This perceptual effect occurs in adults (Raphael, 1972) and in typically developing children (Greenlee, 1980; Krause, 1982); however, vowel duration is not as well established as a perceptual cue in children as it is in adults (Nitttrouer & Lowenstein, 2007). To date, no study has examined the abilities of children with SLI to use this durational cue to final consonant voicing in word contexts, which may entail perceptual, phonological and lexical knowledge.

Lexical effects in speech perception

In adults, the relation between perception and lexical knowledge has been examined using lexical decision and identification tasks with word–nonword (WN) continua (e.g. *dice–tice*; *dype–type*; Ganong, 1980). For the ambiguous stimuli along the category boundaries, subjects were more likely to indicate that they heard the real word rather than the nonword (e.g. *dash* was more likely than *tash* and *tuft* was more likely than *duft*), thus exhibiting a lexical effect. This *Ganong Effect* (i.e. a bias toward perceiving a real word) has been demonstrated in lexical decision studies (Connine & Clifton, 1987; Fox, 1984) and in a phonetic categorization study (Burton, Baum, & Blumstein, 1989) in which the characteristics of the initial consonants were the distinguishing features. Burton et al. (1989) used two identification tasks with 12-step continua (i.e. *duke–tuke* and *doot–toot*) in which voice onset times were the distinguishing features. The lexical effect was present only when the stimuli were more natural and of better quality.

Although most speech perception studies of children with SLI have focused on non-meaningful syllables (nonwords), word contexts add important information and may provide a clearer picture of how speech sound perception relates to lexical representation and processing. In a series of tasks involving categorical perception of words (e.g. *bowl/pole*) and nonword syllables (/ba/, /pa/), children with SLI exhibited poorer discrimination and identification than their typically developing peers for words and for nonword syllables, whether they were synthetic or natural (Coady et al., 2007). Children with SLI performed comparably to their typically developing peers in their identification of digitally edited words when task memory load was minimized, but still somewhat more poorly in discrimination (Coady, Kluender, & Evans, 2005; Coady et al., 2007).

Summary and purpose

Although it seems likely that lexical effects occur in children, this phenomenon has not been examined in children with or without language impairment. We do not know whether children with typical development will be more or less influenced by their mental lexicon when stimuli are ambiguous (i.e. stimuli surrounding the phoneme boundary). We also do not know whether children with SLI will exhibit lexical effects similar to their peers with TLD. The present study extended the examination of temporal speech perception in children by determining the effects of word status on auditory temporal speech perception for children with and without SLI and by investigating the use of vowel duration as a cue to final consonant voicing. We expected children with TLD to use vowel duration as a cue to final consonant voicing characteristic for all continua and to exhibit lexical effects. For children with SLI, we expected deficits in the use of vowel duration as a cue and atypical lexical effects because of a limitation in the ability to use phonological information in this task. However, the direction of the deficits (i.e. stronger vs. weaker lexical effect) for SLI was unknown. If children with SLI exhibit stronger lexical effects than their typically developing peers it would suggest that lexical information drives their identification decisions and may reflect weaker perceptual abilities. If children with SLI exhibit weaker lexical effects it would suggest that their lexical knowledge for these items is less well established and they rely more on their perception of this English-specific vowel duration distinction. These findings may be helpful in elucidating the role of stored lexical

representations for spoken word recognition and vocabulary learning. Group differences in lexical effect (i.e. SLI vs. TLD) may be related to the slow vocabulary growth observed in children with SLI.

Method

Participants

Twenty-six monolingual English-speaking children, ages 6;6–9;9, were recruited. Twelve of the children were diagnosed with SLI, one had LI (because of a low nonverbal IQ – see below) and 13 had TLD. One child with SLI was later excluded because of an inability to complete training. The children were pair-wise age-matched within 3 months across the two groups ($M_{SLI} = 7;7$, $SD_{SLI} = 0;9$); ($M_{TLD} = 7;7$, $SD_{TLD} = 1;0$); $t(23) = 0.012$, $p > 0.05$. All the children resided in the New York City metropolitan area. Parents completed written questionnaires that included information about their educational, vocational, language and ethnic backgrounds, and their children's academic, medical and social-emotional histories.

All of the children were examined by the second author, a clinically certified speech-language pathologist, or by a research assistant, who was completing her clinical fellowship for certification. The examiners administered two standardized tests, a hearing screening and the experimental task to all children.

General inclusion criteria—All the children were monolingual, and had intelligible conversational speech with no apparent expressive phonological impairments. All had unremarkable physical, neurological and social-emotional histories.

Each child also passed a pure tone screening at 20 dB HL for 500, 1000 and 2000 Hz (American Speech-Language-Hearing Association, 1990). They each had normal tympanograms bilaterally defined by peak compliance of 0.2–1.4 cm³/ml, tympanic peak pressure between –150 and 100 daPa, and tympanogram gradient between 60 and 150 daPa (American Speech-Language-Hearing Association, 1990).

All but one child had a performance IQ within normal limits on *The Test of Nonverbal Intelligence – 3rd edition (TONI-3)*: Brown, Sherbenou, & Johnsen, 1997). The average standard scores for the SLI group were 92.2 (SD = 10.0) and for the TLD group the mean was 99.3 (SD = 10.1). The youngest child in the SLI group (6;6) scored a 75. This child's data were ultimately included in the SLI group, because her performance was consistent with the group data (for the 11 children with SLI) for language testing and experimental task performance.

Group identification—Children in the SLI group, nine males and three females, were diagnosed with language impairment and were currently receiving services from a speech-language pathologist. Data are not reported for the one child who could not complete the training portion of the experiment. Each child with SLI also scored below 85 (i.e. more than –1 SD) on one or more composite scores of the *Clinical Evaluation of Language Fundamentals: Third Edition* (see Table 1; CELF-3: Semel, Wiig, & Secord, 1995). Eight of the children had low expressive scores, one had a low receptive score, and three had low

receptive and expressive scores. The children included in the TLD group, seven males and six females, reportedly had age-appropriate grade and reading levels, no history of speech or language impairments, and, as shown in Table 1, composite scores were within the normal range on the *CELF-3* (Semel et al., 1995).

Group comparisons—The groups were similarly diverse socio-educationally based on the similar ranges of parents' educational and occupational experiences (Hollingshead, 1975). The mothers and fathers for each group had median educational levels of some college, with a range from 10th grade to graduate degrees. Similarly, both groups had a wide range of parent occupation levels. The groups also did not differ in performance IQ ($t(23) = 1.777, p > 0.05$).

The SLI group performed more poorly than the TLD group on all language testing. Comparison of the composite standard scores revealed significant group differences for receptive language ($M_{SLI} = 88.3, SD = 9.3$), ($M_{TLD} = 105.3, SD = 8.5$); $t(23) = 4.7677, p < 0.001$, expressive language ($M_{SLI} = 76.0, SD = 9.2$), ($M_{TLD} = 103.1, SD = 7.1$); $t(23) = 7.5439, p < 0.001$ and total language ($M_{SLI} = 80.9, SD = 7.8$) ($M_{TLD} = 103.9, SD = 8.0$); $t(23) = 7.2838, p < 0.001$ composite *CELF-3* scores (Semel et al., 1995).

Stimuli

The auditory stimuli were produced by a female speaker and digitally altered to create four conditions for the experimental tasks. Color pictures were used to represent continuum endpoints for the identification task.

Auditory stimuli—Four consonant–vowel–consonant (CVC) minimal pairs were used to create four sets of 12-step continua. The four continua represented different conditions: (a) word–word (WW: *feet–feed*); (b) nonword–nonword (NN: *zeet–zeed*); (c) word–nonword (WN: *cheat–chead*); and (d) nonword–word (NW: *reat–read*). The initial consonants (C_1) of each minimal pair differed by at least two distinctive features. The final consonants (C_2) were alveolar stops that differed in voicing (i.e. /d/ or /t/). These minimal pairs became the endpoints of the continua. All continua had the same steady state vowel.

The four real words selected appear frequently in adult and third grade level written texts (Carroll, Davies, & Richman, 1971), and in the oral vocabulary of first grade children (Moe, Hopkins, & Rush, 1982). *Read* is most frequent, followed by *feet*, *feed* and *cheat* (Carroll et al., 1971; Moe et al., 1982).

The continua were created by editing selected portions of naturally produced CVCs, the eight endpoint words and nonwords (i.e. *feet*, *feed*, *cheat*, *read*; *chead*, *reat* *zeet* and *zeed*), after first determining the typical temporal characteristics of the segments. The second author, who is a native English speaker from the New York area, digitally recorded five productions of each endpoint CVC. The CVCs were digitized and edited. The editing and creation of the continua were guided by previous studies of vowel duration as a cue to final consonant voicing (Raphael, 1972).

There were 13 tokens in each of the four 12-step continua. A token consisted of $C_1 + V + 85\text{ms stopgap} + C_2$. The same four edited C_1 s were used for all continua. The C_1 for each continuum was created by using altered natural productions. C_1 segments (i.e. /tʃ/, /f/, /r/, /z/) were extracted from four representative utterances. These segments were modified so that each C_1 was 120 ms. Segment durations were determined by the means of the sample utterances.

The cue to the voicing characteristic was vowel duration which varied in 20 ms steps from 110 to 350 ms along each continuum consistent with previous studies of vowel duration and final consonant voicing (Raphael, 1972). The vowels were created from one natural 270 ms /i/ wav file. The same $V + 85\text{ ms stopgap}$ tokens were used for all continua. The tokens were created without the two secondary cues to final consonant voicing: the aspiration and the descending transition that naturally follow the steady state preceding voiced final alveolar stops.

C_2 was an ambiguous final consonant created by extracting the first 15 ms from one natural final consonant /t/ produced in a representative CVC. These 13 sound files ($V + \text{Stopgap} + C_2$) were each copied three more times, yielding four identical sets each containing 13 VC tokens. To these, each of the four C_1 s was added. This yielded four 12-step continua. Stimulus intensity variations were controlled and noise was eliminated. Peak amplitudes of -2.68 dB were maintained for all vowels without frequency clipping. The mean amplitude of the 110 ms vowels was 58 dB and the mean amplitude of the 350 ms vowels was 68 dB SPL. These differences are natural correlates to durational differences.

Visual stimuli—Computer-generated color picture referents (Boardmaker, 1998) for each of the four words and abstract figures for the four nonwords were printed on index cards. A red or blue sticker on each picture corresponded to identical stickers placed on two computer keyboard keys (i.e. the 1 and the 0 keys). During the presentation of each continuum, the pair of pictures was presented on the computer screen above their corresponding keys.

Procedures

Each continuum was presented separately. There were three training phases and a computerized identification task that was designed and presented using *E-Prime* (Psychology Software Tools, Inc., 1999). Data were recorded from categorical key presses for each stimulus presented. It took approximately 1.5 h to administer the training and the four identification conditions for the experimental task.

Training

First, the examiner introduced the referent pictures for each of the stimulus words (*feet*, *feed*, *cheat* and *read*) and nonwords (*zeet*, *zeed*, *chead* and *reat*). Then, the child was asked to point to and name each picture. The child was also asked to describe or define each word, and use each in a sentence. The next training phase required the child to identify each word by selecting its corresponding picture. In the first of these, the children were asked to point to the corresponding picture for each pair (i.e. *cheat/chead*, *reat/read*, *feet/feed* and *zeet/zeed*). The second response required pressing one of two keys that were color coded to

match a corresponding dot on each picture. All children reached the criterion of 3/3 consecutive correct pointing and button press responses. In the third training phase, the paired endpoints for each condition (i.e. WW, NW, WN and NW) were presented through headphones. Each pair was presented in a block of 12 randomly ordered trials with an interstimulus interval (ISI) of 5 s. The training block for each condition was repeated a maximum of seven times to meet the criterion of 10/12 trials correct (binomial distribution $p = 0.016$). The correct pair of pictures for each block was affixed to the computer screen of a PC laptop. Each picture had a red or blue sticker that corresponded to red and blue stickers on the two keyboard response keys. The child was told which endpoint pair would be presented and then responded by key press. The child received verbal feedback after each trial and at the end of each block.

Experiment—After a child reached criterion for a given pair, the experimental identification task for that pair was initiated. The presentation order of the experimental continua was varied randomly across children. Each experimental continuum was presented in three blocks of 26 randomized trials, including two repetitions of each stimulus. The ISIs were 5 s and children had a maximum of 5 s to make a response. Each block was approximately 3.5 min long. There were 78 trials per continuum (26 trials $\times$ 3 blocks = 78 trials). Two versions of the experiment were used to vary the location of responses on the keyboard. Half of the children in each group received Version 1 and half received Version 2. Children were given breaks, snacks and small prizes between blocks to maintain motivation.

Results

All 26 children participated in the computerized training. Data from one child with SLI was excluded because of visual-motor difficulty while pressing the response keys. After five repetitions of one block in Training 2, she expressed frustration and refused to continue. All the other children completed the training and all four conditions of the experimental phase.

Training task analysis

Children with SLI were similar to their TLD peers in learning the acoustic properties of the endpoint stimuli and associating them with the appropriate key press. Children with SLI did not require more training than the TLD children for three of the four continua. There were no between-group differences for mean number of blocks needed to reach criteria, $t(23) p$'s > 0.05 : WW ($M_{TLD} = 4.46$, $SD_{TLD} = 0.88$) vs. ($M_{SLI} = 4.92$, $SD_{SLI} = 1.38$); NW ($M_{TLD} = 4.69$, $SD_{TLD} = 1.11$) vs. ($M_{SLI} = 5.00$, $SD_{SLI} = 0.95$); WN ($M_{TLD} = 4.62$, $SD_{TLD} = 0.96$) vs. ($M_{SLI} = 4.83$, $SD_{SLI} = 1.27$). For one condition, NN, SLI children required slightly more training than the TLD group ($M_{TLD} = 4.08$, $SD_{TLD} = 0.28$), ($M_{SLI} = 4.58$, $SD_{SLI} = 0.79$); $t(23) = 0.9930$, $p = 0.04$, $d = 0.94$. This between-group difference was less than one block.

Experimental task analysis

Because this study examines a near-continuous variable (i.e. vowel duration), probit analysis, which is a linear duration-response curve of the form $a + b * duration$, was used to determine the response distributions of the SLI and TLD groups for all four continua. Predicted mean percentages of CV/t/responses were calculated at 80% (0.80 probability

level), corresponding to the area of certainty for the short vowel end of the continuum (e.g. *feet*); 65% (0.65 probability level), within the area of uncertainty (e.g. *feet*-like), 50% (0.50 probability level), for the category boundary (e.g. stimuli between *feet* and *feed*), 35% (0.35 probability level), within the other area of uncertainty (e.g. *feed*-like) and 20% (0.20 probability level), corresponding to the area of certainty for the long vowel end of the continuum (e.g. *feed*).

Group and condition comparisons were made by applying *t*-tests to the defined probit points. These points were the vowel durations at which the response rates were 80%, 65%, 50%, 35% and 20%. All findings reported as significant have been adjusted for multiple tests (i.e. the corrected 0.01 alpha level, $p = 0.0005$, and the corrected 0.05 alpha level, $p = 0.0023$).

Vowel duration as a cue—The overall directions of the four identification functions indicate that both groups approached 100% CV/t/ responses at short vowels and approached 0% CV/t/ responses at long vowels (see Figure 1). In general, the children used vowel duration as a cue to the voicing characteristic of the final consonants. Short vowels showed better responses overall than long vowels. This is most likely an artifact of stimulus creation because the downward transition for long vowels was deleted in order to remove any additional cues specific to voiced final consonants. Nevertheless, there were group differences in the areas of certainty, uncertainty and category boundary.

Of the four continua tested, the SLI group performed most similarly to the TLD group on the WW (i.e. *feet*–*feed*) continuum differing only in responses at the area of certainty at the short vowel end of the continuum (see below). All other aspects of the WW function did not show group differences. For the NN and NW continua, group differences were observed from the short vowel end of the continuum through the category boundary. The WN continuum yielded no between group differences at the short vowel end of the continuum. However, differences were observed at the category boundary throughout the long vowel end of the continuum (see Figure 1).

Areas of certainty—In categorical perception tasks with two-alternative-forced-choice designs, preferential selection of one response choice at the ends of continua is expected. This preference indicates response certainty. In the current study, probit analysis predicted the vowel durations at which response certainty (CV/t/ response rates were equal to or greater than 80% and equal to or less than 20%) was reached for each group and for each continuum. Figure 1 shows that mean certainty was reached for the WW continuum, by the TLD group at 169.5 ms (SE = 5.3) at the *feet* end of the continuum, and at 310.8 ms (SE = 5.8) at the *feed* end of the continuum, whereas certainty was reached by the SLI group at 139.8 ms (SE = 7.6), and at 315.5 ms (SE = 7.5), respectively. There was a large effect size difference for the short vowel ($t(21) = 3.1933$, $p = 0.0014$, $d = 1.31$), and no difference for the long vowel ($p > 0.05$). Similar group differences were observed for the zeet–zeed and reat–read continua. The TLD group showed certainty (i.e. 80% or greater response rates) closer to the category boundary for zeet ($M_{zeet} = 155.0$; SE = 8.0), and reat ($M_{reat} = 121.9$ ms; SE = 8.8) for the longer vowel durations than the SLI group ($M_{zeet} = 102.9$ ms, SE = 12.7; $M_{reat} = 41.7$ ms, SE = 18.7), respectively, $t(21) = 3.4618$, $p = 0.0005$, $d = 1.2$; and $t(21) = 3.8717$, $p = 0.0001$, $d = 1.57$). There were no differences between children with TLD

($M_{zeed} = 362.4$ ms, SE = 10.6; $M_{read} = 315.9$ ms, SE = 7.9) and with SLI ($M_{zeed} = 350.1$ ms, SE = 12.3; $M_{read} = 312.6$, SE = 11.2) in certainty responses for the longer vowels (p 's > 0.05).

For WN, the 80% probit point at the short vowels end of the continuum (i.e. the *cheat* end) did not differ between groups ($M_{TLD} = 173.6$, SE = 4.6); ($M_{SLI} = 164.2$, SE = 7.1); $p > 0.05$, whereas the response certainty at the long vowels end of the continuum (i.e. the *chead* end) differed. The children with SLI reached mean certainty at a vowel duration of 347.0 ms (SE = 9.1) and the children with TLD reached mean certainty at 295.1 ms (SE = 4.8) ($t(21) = 5.0700$, $p < 0.0001$, $d = 2.06$).

In summary, for three of the continua (WW, NN and NW), the SLI group reached certainty at shorter vowel durations, indicating a different certainty point (i.e. category boundary) for CV/t/, than the TLD group. For one continuum (WN), there was no group difference for point of certainty at the short vowel end (i.e. *cheat*). However, for the long vowel end of the continuum (i.e. *chead*) children with SLI reached certainty at a longer vowel duration than the TLD group.

Phoneme perception boundaries—In categorical perception tasks, tokens in the midpoints of continua are ambiguous and equivocal responses are expected. A response rate with a 50% probability determines the phoneme perceptual boundary. Probit analysis was used to determine the phoneme boundary (the group mean for the vowel duration at which the probability of a CV/t/ response was 50%) for each continuum. We found group differences for three of the four continua: NN, NW and WN. Category boundaries for NN and NW continua were at shorter vowel durations for the SLI group than for the children with TLD. For *zeet–zeed*, the mean SLI category boundary was 226.5 ms (SE = 6.3) and the mean TLD boundary was 258.7 ms (SE = 5.5), $t(21) = 3.8641$, $p = 0.0001$, $d = 1.55$. For *reat–read*, the mean SLI category boundary was 177.2 ms (SE = 8.2), and for children with TLD it was 218.9 ms (SE = 4.9), $t(21) = 4.3602$, $p < 0.0001$, $d = 1.81$. The mean category boundary for *cheat–chead* was longer for the children with SLI than for the children with TLD ($M_{SLI} = 255.6$ ms, SE = 5.0), ($M_{TLD} = 234.4$ ms, SE = 3.4); $t(21) = 3.5071$, $p = 0.0005$, $d = 1.44$. There was no group difference for *feet–feed* ($M_{SLI} = 227.7$, SE = 4.7); ($M_{TLD} = 240.2$, SE = 3.8); $t(21) = 2.0748$, $p > 0.0023$.

Areas of uncertainty—Identification performance was also examined in the areas where tokens were ambiguous (i.e. response uncertainty). Probit analysis was used to sample two points in each continuum: the 0.65 probability and the 0.35 probability of a CV/t/ response (i.e. 65% and 35% CV/t/ responses). Here again there were group differences for the NN and NW continua at the short vowel end. The children with SLI reached the 0.65 probability response rate (PRR) at a mean vowel duration of 169.9 ms (SE = 8.2) for *zeet* whereas the TLD group reached it at a mean vowel duration of 211.2 ms (SE = 5.6), $t(21) = 4.1799$, $p < 0.0005$, $d = 1.70$. Similarly, the children with SLI reached the 0.65 PRR at a mean of 115.2 ms (SE = 12.4) for *reat*, and the children with TLD reached that PRR at a mean of 174.5 ms (SE = 6.1), $t(21) = 4.2789$, $p < 0.0005$, $d = 1.83$. For *feet*, the groups performed similarly; the children with SLI reached the 0.65 PRR at a shorter vowel duration ($M_{SLI} = 187.5$ ms, SE = 5.5) than the children with TLD ($M_{TLD} = 207.8$ ms, SE = 4.1), approaching the

corrected value for significance, $t(21) = 2.9876$, $p = 0.0028$, $d = 1.2$. At the long vowel end, although responses for *read* and *zead* approached uncorrected significance (p 's < 0.05), only the *chead* responses yielded a significant group difference at the 0.35 PPR ($M_{SLI} = 297.5$ ms, $SE = 6.4$); ($M_{TLD} = 262.2$ ms, $SE = 3.7$), $t(21) = 4.7549$, $p < 0.0001$, $d = 1.99$.

Lexical effect—In WN continua, a preference for selecting the real word (i.e. as indicated by a category boundary shift away from the real word) indicates a lexical effect (Ganong, 1980). In the current study, both groups demonstrated a lexical effect for the WN and the NW continua. For children with SLI, the mean difference between the NW ($M_{SLI} = 177.2$ ms, $SE = 8.2$) and the WN ($M_{SLI} = 255.6$ ms, $SE = 5.0$) category boundaries (i.e. at the 0.50 PPR) was 34.4 ms ($SE = 9.2$), $t(21) = 2.3936$, $p < 0.05$, $d = 3.43$. For the TLD group, the mean difference between the NN ($M_{TLD} = 218.9$ ms, $SE = 4.9$) and the WN ($M_{TLD} = 234.4$ ms, $SE = 3.4$) category boundaries was 20.7 ms ($SE = 9.2$), $t(21) = 2.2496$, $p < 0.05$, $d = 3.74$. The difference in effect sizes indicates a much stronger lexical effect for children with SLI than for their typically developing peers. Further evidence of a stronger lexical effect for children with SLI came from their more frequent identification of continua tokens on the nonword side of their category boundaries as real words (see Figure 1 and previous section) in the WN and the NW continua (p 's < 0.0005). The WW vs. NN continua did not yield a boundary shift for either group (p 's > 0.05) as we had expected.

Age effects—There was an overall age effect; older children (above the median split of 7;5–89 months) were always more likely to give a /t/ response at shorter vowel durations, with the crossover varying with the pair. There was a group by age interaction, but as is apparent in Figure 2, it resulted only from the *cheat–chead* continuum for the older children with TLD. The older children with TLD exhibited a higher proportion of *cheat* responses throughout the continuum with only a gradual linear decrease as vowel duration increased. The remaining stimuli did not reveal age differences.

Summary

Children with SLI were able to recognize and identify endpoint stimuli similarly to their TLD peers, but reached certainty at different points along the continua. Children with SLI needed more durational difference than their TLD peers to make the certain identification. Additionally, children with SLI showed category boundaries at shorter vowel durations for three of the continua, and at longer vowel duration for one (*cheat–chead*). Both groups demonstrated lexical effects in the WN and NW continua. Children with SLI had stronger lexical effects than the TLD group. The children with SLI were most similar to the TLD group for the WW (i.e. *feet–feed*) continuum.

Discussion

The current investigation extends previous speech perception research in children with SLI by examining the relation between the perception of a temporal speech cue (i.e. vowel duration as a cue to final consonant voicing) and lexical knowledge (i.e. word status) in an identification task. Children with SLI did not differ from their TLD peers in the amount of training they needed to learn the experiment task. They did not have the difficulty reported

elsewhere for other perception tasks (Robin, Tomblin, Kearney, & Hug, 1989). The identification task employed digitally edited natural speech and had minimal working memory demands (Coady et al., 2005, 2007). Therefore, group differences cannot be attributed to overall task performance asymmetries.

For the four continua, all of the children used short vowels as a cue for CV/t/ and long vowels as a cue for CV/d/ as in adults (Raphael, 1972). However, the children with SLI were less consistent than their TLD peers. Their performance was most similar to the TLD group for the WW (*feet–feed*) continuum. Otherwise, they exhibited less certainty overall (larger areas of uncertainty), and stronger lexical effects than the TLD group for the WN (*cheat–chead*) and NW (*reat–read*) continua.

Because their responses to the WW (*feet–feed*) continuum were similar to the control group, we can surmise that children with SLI used phonological representations in long-term memory to support the use of vowel duration for phoneme and lexical identification. However, it would be erroneous to assume that children with SLI acquire typical and stable phonological representations for familiar words as has been suggested (Coady et al., 2005). If this were the case, then their responses to *feet*, *read* and *cheat* should have been similar to the TLD group; only the NN (*zeet–zeed*) continuum would have shown differences. Only one of the real words (*feed*) actually showed similar responses. A greater range of uncertainty was evident in the WN and NW continua as well as the NN continuum. Further, the stronger lexical effect shown as preferences for real words on the nonword side of the phoneme boundaries indicate that children with SLI have unstable phonological representations for words as well as for nonwords as evidenced by the over-selection of *read* and *cheat*. Only under controlled conditions, where the context limited lexical selection (i.e. in this case a two-alternative forced choice task in which both ends of the continuum were familiar words, *feet–feed*), do they recognize words in the same way as their peers. Thus, in all other cases, children with SLI used the vowel duration cue differently than their typically developing peers.

Further research is needed to investigate how these children use other acoustic cues to phonemic distinctions in English and in other languages. Children with SLI may differ from their TLD peers in their acoustic weighting strategies (Nittrouer & Lowenstein, 2007). The current study demonstrated their preference for lexical rather than vowel duration information. However, vowel duration may not be as salient a cue as some other acoustic cues (see Nittrouer & Lowenstein, 2007 for a review). Children with SLI may be more attuned to other cues. Further research is needed to identify those acoustic cues or contexts that are more salient to children with SLI, and that may supersede lexical preferences. Such data would determine which cues and under what conditions novel words are recognized as novel, thus normalizing the lexical effect.

Because children with SLI have more limited vocabularies or less detailed lexical representations than their peers, their use of acoustic weighting strategies may be under-developed. They may require more interrelated contextual cues than children who are TLD. The contextual cues that most benefit children's lexical development as they learn to segment the speech stream into words, syllables and segments remain unknown.

Identification paradigms similar to the one used in the current study have been used with adults to explore a variety of word and sentence contexts (Borsky, Tuller, & Shapiro, 1998; Connine & Clifton, 1987) and could be used to explore acoustic, phonological, lexical and sentence processing in children with SLI.

These results may also be related to other findings regarding SLI. Children with SLI were more likely than their dyslexic and typically developing peers to accept altered words regardless of whether or not they were in contexts (e.g. *brown(m) bell* vs. *brown(m) lamp*) that led to potential assimilation (Marshall, Ramus, & van der Lely, 2010). The common finding that children with SLI perform more poorly on nonword repetition may also reflect indirectly a tendency to identify tokens as instances of related real words leading to incorrect repetitions.

Our findings indicated that when presented with a new CVC word (nonword in this experiment), children with SLI were more likely to assume that it is a word with which they are familiar, rather than recognizing it as a new word they need to learn. For example, if *chead* were a new real English word in a sentence, but was identified by a child as the familiar word, *cheat*, the child would attach incorrect meanings and usages to *chead*. Lexical acquisition would therefore be negatively affected (Edwards & Lahey, 1996). This may, in part, contribute to the poor semantic knowledge demonstrated in children with SLI (McGregor, Newman, Reilly, & Capone, 2002). In auditory lexical processing and access, word forms are processed through the phonological system first even if the task is semantic. Further research is needed to explore the direct effect of phonological errors in lexical identifications on semantic-based lexical access and lexical development in children with SLI.

Importantly, the results of this investigation contribute to our understanding of the underlying cause of the perceptual deficits demonstrated in children with SLI. Although many researchers agree that children with SLI have impaired speech perception (Bishop et al., 1999; Gathercole & Baddeley, 1990; Leonard, 1989; Leonard et al., 1992; Mody, Studdert-Kennedy, & Brady, 1997; Sussman, 1993; Tallal et al., 1993), there is disagreement as to the nature and underlying cause of the deficits. The auditory temporal processing view attributes phonological misrepresentations to abnormalities of the lower level auditory system (see Tallal et al., 1993). In this view, children with SLI have auditory systems that are unable to process temporal characteristics of brief, rapidly sequenced, or subtly different acoustic signals. The cognitive–linguistic view assumes that children with SLI have normal auditory systems, but have deficits in their abilities to recognize speech sounds accurately leading to phonological, lexical and morphosyntactic deficiencies. In short, the disagreement is whether phonological misrepresentations can be attributed to processing deficits in the auditory system or in the cognitive–linguistic system (Mody et al., 1997; Studdert-Kennedy et al., 1994; Sussman, 1993). Our findings do not support the presence of an auditory level deficit for vowel duration. Specifically, contrary to previous studies, the children with SLI were able to discriminate fine temporal distinctions (Elliot & Hammer, 1988; Tallal & Stark, 1981). This occurred for the *feet–feet* continuum. For this continuum, children with SLI had slowly sloping identification functions similar to their TLD peers; both groups had similar sensitivity to the 20 ms differences in vowel duration. If

the perceptual deficit is on the auditory level, children with SLI should not have been able to perceive any of the continua similarly to the children who were TLD.

We also found that duration of the temporal cue (Tallal et al., 1993) was irrelevant. The vowel duration cues examined in this study (i.e. 110–350 ms) were longer than transition durations or vowel durations used in most previous studies (Frumkin & Rapin, 1980; Tallal & Piercy, 1975), and yet, children with SLI had less accurate identification at both ends of the continua. Long and short vowels were poorly categorized depending on the particular continuum. Rather than a fundamental perceptual deficit for duration, vowel duration had limited value as a cue for final consonant voicing in children with SLI. The poor use of this cue in the presence of adequate fine discrimination is consistent with previous findings for some spectral cues. For example, children with SLI have adequate discrimination and poor identification of syllables /ba/ vs. /da/ (Bishop, Hardiman, Uwer, & von Suchodoletz, 1997; Sussman, 1993). Poor use of cues for categorizing segments may result in atypical phonological representations (Bishop et al., 1997; Gathercole & Baddeley, 1990; Sussman, 1993).

In summary, the current study lends support to the view that the perceptual deficits associated with SLI reflect cognitive-linguistic factors (Sussman, 1993) rather than auditory processing (Tallal et al., 1993). Further, it suggests that phonetic cues are over-ridden by linguistic information causing some phonological representations to be atypical.

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Figure 1.

Probability of response rates at vowel durations by continua and group. This figure shows the mean SLI (●) and TLD (△) identification functions as fitted response curves based on the probit analysis for WW (*feet-feed*), NN (*zeet-zeed*), WN (*cheat-chead*) and NW (*reat-read*). Dotted lines represent the duration of responses at 80%, 50% and 20% identification, respectively, for each group. Error bars are extended to two standard errors on either side of durations where appropriate.

Figure 2.

Fitted response curves and critical durations of (a) *cheat-chead*, (b) *feet-feed*, (c) *reat-read* and (d) *zeet-zeed* by age and group.

Table 1

Group demographics and standard scores.

SLI		CELF-3 ^a		
Age	Gender	TONI-3 ^b	RLS ^c	TLS ^e
6;6	M	75	94	65
6;7	F	107	92	78
6;7	M	87	84	78
6;11	M	85	84	90
7;2	F	81	75	82
7;5	M	97	94	75
7;9	F	95	69	53
8;1	M	95	88	78
8;4	M	95	94	78
8;8	M	110	90	82
8;9	M	89	104	78
9;6	M	90	92	75

TLD		CELF-3 ^a		
Age	Gender	TONI-3 ^b	RLS ^c	TLS ^e
6;6	F	89	110	120
6;8	F	102	108	96
6;8	M	100	100	96
6;11	M	117	116	116
7;1	M	100	108	108
7;2	F	100	104	108
7;4	M	116	116	104
7;9	F	100	106	96
8;1	F	90	116	110
8;3	M	81	86	100
8;9	F	103	100	92
9;4	M	102	102	98

9;6	M	91	98	96
<hr/>				
^a CELF-3; Semel et al. (1995).				
^b TONI-3; Brown et al. (1997).				
^c Receptive Language Score.				
^d Expressive Language Score.				
^e Total Language Score.				