SPEECH PERCEPTION AND LEXICAL EFFECTS

IN SPECIFIC LANGUAGE IMPAIRMENT

THE EFFECTS OF VOWEL DURATION AND WORD KNOWLEDGE

ON PERCEPTION OF FINAL ALVEOLAR STOP VOICING

by

FRANCES L V SCHEFFLER

A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

2002

UMI Number: 3063880

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

This manuscript has been read and accepted for the Graduate Faculty in Speech and Hearing Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

9/17/02

Date

Richard G. Schwartz, Ph.D., Chair of Examining Committee

9/17/02

Date

Robert Goldfarb, Ph.D., Executive Officer

Lawrence Raphael, Ph.D., Supervisory Committee

Valerie Shafer, Ph.D., Supervisory Committee

Judith Gravel, Ph.D., Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

Abstract

SPEECH PERCEPTION AND LEXICAL EFFECTS IN SPECIFIC LANGUAGE IMPAIRMENT: THE EFFECTS OF VOWEL DURATION AND WORD KNOWLEDGE ON PERCEPTION OF FINAL ALVEOLAR STOP VOICING

by Frances L. V. Scheffler

Advisor: Richard G. Schwartz

The perception of temporal speech cues, lexical knowledge, and their interactions were examined in children (6;0-9;6) with specific language impairment (SLI). An identification task was used to test four 12- step speech continua: word-word (FEET—FEED), nonword-nonword (ZEET— ZEED), word-nonword (CHEAT — CHEED) and nonword-word (REAT – READ). The stimuli were naturally recorded and digitally edited. The vowel steady state, which varied in duration from 110 to 350 milliseconds in 20-millisecond steps, was the acoustic cue to the voicing characteristic of the final consonant in each stimulus. The analyses revealed that both the TLD and SLI groups used vowel duration as a perceptual cue. For the word-word condition, SLI and TLD did not differ in their responses. There were group differences for the three remaining continua. For the nonword-nonword condition, the word-nonword and the nonword-word conditions, SLI demonstrated less response certainty than their TLD peers. In addition, children with SLI had different category boundaries than the TLD group. Both groups demonstrated a word bias effect, however, it was stronger for the SLI group. Therefore, children with SLI use vowel duration as a cue to the final consonant voicing characteristic, however the use of this cue is weak: their perceptual judgments are influenced more readily by higher-level lexical knowledge than children who are TLD.

Acknowledgments

The complex process of developing into a scholar worthy of a Ph.D. involves focus, commitment, and time. These have all been possible for me because of the continuous encouragement of family, friends, mentors, and colleagues.

My husband, Allan, is a wise and enthusiastic supporter, whose devotion and respect have been essential to me during the pursuit of the doctoral degree. My children, Eric, Jill, and Elizabeth, have been collectively a solid source of great pride; and individually, have been profound sources of constant joy. Their love, affection, good humor, and willingness to share the household chores, act as "pilot subjects", and share their bedrooms with my computer, books, journal articles, and never-ending "final drafts" have allowed me to be an effective mom and a serious student simultaneously. I am grateful to my family for their loving support, for their willingness to take good care of themselves, and for their abilities to be the best they can be at all times. I am proud of them, as I know they are proud of me!

Richard Schwartz is a gifted and generous mentor, and an inspirational researcher. He has provided me with an environment in which to develop as a focused, disciplined, and thoughtful student of science. I will be forever grateful to him for his willingness to share his extensive knowledge in the areas of typical and atypical child language as well as in the areas of grantsmanship and publishing. I thank him profusely for the opportunities he has provided.

Larry Raphael has taught me most of what I know about speech science. I have a lot more to learn, but his expertise and his good humor have been important influences on my academic development. Judy Gravel and Valerie Shafer have contributed refinement to my work. They have helped me pay attention to details that otherwise would have gone unnoticed. They have influenced my thinking about the relationships between theory and practice, about hearing and language, about disorder and normalcy.

In addition, I thank the people who have helped me move forward at various stages in this process: Loretta Walker, executive secretary for the Department of Speech and Hearing Sciences at the Doctoral Center of CUNY; the wonderful people at the Albert Einstein College of Medicine: Diane Slonim, Nassima Abdelli, Sandy Ramos, Susan Bohl all of the speech-language laboratory; Martha Ann Ellis and WeiWei Lee, research audiologists; Judy Kreuzer, electrophysiology technician; Haftan Eckholdt, Director of Biometrics. In addition, thank you Eric Rosenberg, statistical advisor; and Eileen Baer, research librarian in Bedford Hills, NY. All these people have made important contributions to my work. They have made my efforts productive, worthwhile and possible.

Finally, I dedicate this dissertation and all that it symbolizes to the blessed memory of my father, Mac Victor. He was a loving person and positive force to all who knew him. He lived fully and kindly, and loved unconditionally. Among the messages of his life are: Celebrate simply and from the heart. Love wholly and from the soul. Live passionately and with gusto. Wear rose-colored glasses and be certain that you see the world clearly through them.

This dissertation represents my best efforts to reflect my father's message, my husband's counsel, and my colleagues' teachings. Thank you all!

This work was supported by NIH-NIDCD Grant # DC00223 and by the PSC-CUNY Research Award Program.

Table of Contents

List of Tables

List of Figures

List of Appendixes

Introduction

Specific language impairment (SLI) is a developmental disorder that affects approximately seven percent of school-aged children (Plante, 1998) This disorder is characterized by slow vocabulary and syntactic development that cause learning and reading disabilities in the absence of cognitive, neurological, social-emotional, or hearing impairments (Leonard, 1998).

The cause of SLI has been the focus of several studies over the past 30 years Several researchers hypothesize that many children with SLI have an auditory processing disorder that interferes with the development of phonological representations (Gathercole & Baddeley, 1990, Leonard, 1989, Leonard, McGregor, & Allen, 1992; Mody, Studdert-Kennedy, & Brady, 1997, Sussman, 1993, Tallal, Miller, & Fitch, 1993) Although there is ample evidence to support this view at a general level, there is controversy regarding the exact nature of the processing deficits that cause atypical phonological representations

Impaired auditory temporal processing account

One view is that children with SLI suffer impaired auditory perception for the temporal features of speech sounds (see Leonard, 1998, Tallal, Miller &. Fitch, 1993 for reviews). In this view, children with SLI have difficulty differentiating between speech sounds for which the distinguishing feature is brevity A number of studies have reported that children with SLI have insensitivity to small durational differences during discrimination tasks (Elliott & Hammer, 1988, Tallal & Piercy, 1974; Tallal, Stark, Kallman, & Mellits, 1980; Frumkin & Rapin, 1980), and inaccurate serial ordering in temporal order judgment (TOJ) tasks (e.g., Tallal & Piercy, 1974, 1975; Tallal, Stark, Kallman, & Mellits, 1980; Tallal & Stark, 1981; Frumkin & Rapin, 1980; Stark & Heinz, 1996). The atypical response patterns to discrimination and TOJ tasks have been described as impairments in temporal auditory processing for brief cues (Tallal, Miller, & Fitch, 1993), or as disorders of "fine-grained discrimination" (Elliott & Hammer, 1988). Studies that have examined temporal deficits have used a variety of cognates and wordshapes (e.g., Vowel and minimally different consonant-vowel, consonant-vowel-consonant syllable pairs, and multi-syllabic stimuli) and have focused on a few temporal features (e.g., Voice onset time: Elliot & Hammer, 1988; transition durations: Bradlow, Kraus, Nicol, McGee, Cunningham, Zecker, & Carrell, 1999, Frumkin & Rapin, 1980, Tallal & Piercy, 1974, 1975, Sussman, 1993; inter-stimulus intervals: Tallal, 1976, Tallal & Piercy, 1973a, 1973b, 1975; and vowels: Stark & Heinz, 1996). Of particular interest are deficits related to vowel duration. Children with SLI vary in their ability to discriminate and identify vowels. When vowel durations are long (i.e., 250ms), children with SLI successfully identify and sequence minimally distinct vowels (Frumkin & Rapin, 1980; Tallal & Piercy, 1974; Tallal & Stark, 1981). However, when vowels are relatively short (i.e., 40-100ms), identification performance is influenced by context. For example, children with SLI were similar to children with TLD for identification of /i/ versus /u/ in isolation (100ms), but they were less accurate when these vowels were of the same duration but unstressed (and therefore brief relative to the stressed syllables) in multi-syllabic nonwords (e.g., /dabiba/ versus /dabuba/; Leonard, McGregor & Allen, 1992). In addition, although children with SLI identified syllables /dab/ versus /daeb/

with the same degree of accuracy with 40ms vowels (Leonard et al., 1992; Tallal & Stark, 1981), they were less accurate for identification of 43ms /ɛ/ versus /æ/ preceding 207ms /I/ (Tallal & Piercy, 1975). Therefore, vowel categorization in SLI appears vulnerable in certain contexts.

Limitations of the auditory temporal processing account

Although there is ample evidence that temporal features of speech pose processing problems for children with SLI, the significance of this finding has been an area of controversy. Inadequate controls (Studdert-Kennedy, Liberman, Brady, Fowler, Mody, & Shankweiler, 1994), invalid testing procedures (Bishop et al., 1997), and improper interpretations of the results (Studdert-Kennedy et al., 1994; Bishop, Carlyon, Deeks, & Bishop, 1997) confound the interpretation of these studies. The primary supporting evidence for the temporal deficit hypothesis comes from a paradigm known as the Auditory Repetition Task (ART) (Tallal & Piercy, 1973a & 1973b, 1974, Stark & Tallal, 1981, Bishop et al., 1997). This task requires a participant to engage in a sequence of subtests that provide training and testing for identification and short-term sequential memory for two endpoint speech nonword stimuli (i.e., nonword-vowels or consonant-vowel combinations). The stimulus pairs used were minimally distinct for their temporal and/or spectral characteristics (e.g., Commonly used speech pairs were /ba/-/da/; /ba/-/pa/; /i/-/I/; /I/-/ɛ/). The experiments used a criterion-based response measurement.

Children with SLI were unable to reach criteria either for brief stimuli or for those presented with brief inter-stimulus intervals. Studies using ART provide evidence that children with SLI indeed have deficits in identifying minimally distinct segments.

However, many of these studies do not isolate temporal versus spectral features, nor do they isolate the level of the deficit (Studdert-Kennedy et al., 1994). They do not determine whether the underlying cause of the deficit is in processing the acoustic features, or in assigning a label to the stimulus after the acoustic features have been perceived (Studdert-Kennedy et al., 1994)

In addition, although deficits in perception of temporal features have been described for children with SLI, the cues examined have been limited to a few isolated acoustic features of individual segments (Studdert-Kennedy, et al., 1994) In particular, there are many temporal features of speech sounds that have not been examined No studies, to date, have investigated any of a variety of contextual temporal cues that are available during speech perception The difficulties experienced by children with SLI in determining the phonological composition of utterances cannot be explained adequately by the exclusive examination of brief within-segment cues (e.g., stimuli that differ by 40-ms transitions such as synthetic /ba/ vs. /da/) as has been emphasized by several researchers (e.g., Tallal & Piercy, 1973a, 1973b, 1974, Frumkin & Rapin, 1980) Rather, a more extensive examination of perception in children with SLI that includes contextual temporal cues is important (Studdert-Kennedy et al., 1994).

Perhaps the most significant weakness of the impaired auditory temporal processing account is that it has not been directly linked to any of the morphosyntactic, lexical, or syntactic deficits in SLI. The only link is the observation that these children have poor perception of vowels in the context of brief, unstressed medial syllables of multisyllablic nonwords (Leonard et al., 1992). No studies to date have expanded the examination of vowel perception to the word level in children with SLI.

Vowel duration as a contextual cue

One contextual cue is vowel duration, which acts as a perceptual cue to final consonant voicing. In an identification experiment with word-word continua varying in vowel duration (e.g., BET-BED, GAPE-GABE), adults categorized tokens with long vowels as having voiced final consonants, and those with short vowels as having voiceless final consonants (Raphael, 1972). Young children also use vowel duration as a cue to final consonant voicing (Greenlee, 1980; Krause, 1982). Greenlee used four minimal pairs (BACK-BAG; BERT-BIRD; BUS-BUZZ; CUP-CUB); Krause employed twelve step continua in identification tasks contrasting three word pairs (BIB-BIP, POT-POD, and BACK-BAG). Both studies confirmed that six-year-old children use vowel duration as a cue to final consonant voicing.

The use of vowel duration as a cue to final consonant voicing characteristics has not been studied in children with SLI. The impaired vowel representations shown in previous research in this population indicate that the contextual use of vowel duration may be limited (Leonard et al. 1992; Tallal & Piercy, 1975, Tallal & Stark, 1981; Stark & Heinz, 1996). This limitation may lead to atypical categorization of final consonants. Thus, representations for final consonants in relevant lexical items might be distorted.

Impaired language processing accounts

Another view of the cause of phonological misrepresentations is that a disturbance occurs on the linguistic level of processing. In this view, acoustic-phonetic perception (i.e., discrimination) is in tact, however, speech is poorly encoded (Sussman, 1993). Poor ability to associate acoustic-phonetic information with phonological representations stored in long-term memory interferes with word recognition and access (Edwards & Lahey, 1996; Sussman, 1993; Bishop et al., 1997). These deficits have been demonstrated in vowel (Stark & Heinz, 1996) and syllable identification (Elliott & Hammer, 1988; Sussman, 1993), and in imitation (Gathercole & Baddeley, 1990) tasks. Sussman (1993) found atypical identification in children with SLI for tokens of a seven step spectral (i.e., /ba/-/da/) continuum. Category boundary shifts, preference for a /ba/ response, and greater response variability was observed. In a task designed to measure just noticeable differences (JNDs), children with SLI exhibited larger discrimination thresholds for CVs differing in VOT than their TLD same-age peers (Elliott & Hammer, 1988). On closer examination, these fine discrimination differences, actually represent identification differences. The TLD group and the SLI group discriminated differences between tokens only across the category boundary. SLI children needed a larger cross-boundary difference than TLD children, suggesting a between-group difference in boundary (cf. Sussman, 1993).

A large body of literature (e.g., Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1990; Montgomery, 2002) has revealed phonological working memory deficits in children with SLI. These deficits are revealed in children's poor repetition of multisyllabic nonwords and words that increase in length. For example, in a series of nonword imitation tasks, Gathercole & Baddeley (1990) reported that 6-year-old children with language impairments performed like 4-year-old children with TLD in response accuracy Gathercole & Baddeley also tested imitation of words of increasing syllable length In these tasks, children with SLI demonstrated poorer recall as number of syllables increased Their poor performance on this series of imitation tasks was attributed to an inability to hold phonological units in short-term phonological memory long enough to match them to long-term representations (Gathercole & Baddeley, 1990; Baddeley, Gathercole, & Papagno, 1998).

Limitations of both accounts

Both views posit that inaccurate segment identification distorts mental representations of lexical entries during word learning They do not agree on the cause The impaired auditory temporal processing account supports the position that children with SLI have deficits in perception of brief or rapidly changing portions of segments However, some of the stimuli used to demonstrate this view, include segments that combine temporal and spectral characteristics (e.g., /ba/ vs /da/ with transition duration changes) The cue value of spectral information is ignored in these studies Further, the ART paradigm used to demonstrate temporal deficits has numerous design flaws (see Studdert-Kennedy et al., 1994, Bishop et al., 1997)

The impaired language processing accounts are also limited by the stimuli and by the nature of the tasks The stimuli were not controlled for acoustic-phonetic segment characteristics Therefore, a systematic analysis of the relationship between the imitation errors reported and the acoustic characteristics of the stimuli is not possible Furthermore, the use of oral verbal imitation adds an articulatory performance factor that confounds the interpretation Although oral imitation tasks allow a general examination of perception-production relationships, they do not provide an opportunity to separate deficits in perception from deficits in production.

Previous studies that address phonological processing in SLI promote a bottom-up hierarchy in which speech information is coded modularly and linearly from auditory to phonetic to phonological level (see Connine & Clifton, 1987). None of the previous studies account for the top-down influences of the already established mental lexicon on speech perception as in adults (Ganong, 1980; Lahiri & Marslen-Wilson, 1991). Speech can be represented on syllable or word levels in adults, depending on the demands of the task (see Sendlmeier, 1995 for a review). There are no studies to date that examine representational levels in children. It is important to determine if perception on the word level differs from the syllable level in children. Further, it is essential to compare perception of words and syllables in children who are SLI with children who have typically developing language (TLD). Differential patterns of word perception and nonword perception will elucidate the relationships among perception, lexical encoding, lexical representation, lexical processing, and some of the language deficits in SLI.

Bottom-up and top-down processes interact to form phonological representations

Phonological representations are listeners' interpretations of acoustic signals that are stored in long-term memory. They are used as templates in order to recognize speech as units of the language despite talker and contextual variability. Phonological representations develop during infancy and childhood, and are based on a complex relationship between innate and learned mental operations that allow listeners to group acoustic-phonetic segments into categories (see Kuhl, 1991; Miller, 1994 for reviews). Members of these categories are linguistically equivalent but differ acoustically.

The specific mechanisms that underlie the mental operations that result in phonological representations remain unknown. However, a series of mental operations occur that apply inclusionary and exclusionary criteria within the three physical domains so that features, segments, syllables, and words can be recognized (see Nygaard & Pisoni, 1995 for a review). These mental operations allow new signals to be compared to old ones stored in long-term memory. The mental operations combine sensory (i.e., auditory and visual), perceptual, and cognitive-linguistic processes. When a speech signal is heard, the listener encodes it into a phonological representation while determining its status as a word or nonword. Disturbances in any of the mental processes may impair phonological representations. If acoustic-phonetic events are discriminated, categorized, or encoded improperly by a listener so that segment families contain atypical members, mental representations of segments for that listener will be impaired. Misrepresented segments are posited to affect higher order language systems resulting in a cascade of deficits in morphophonology (Leonard, McGregor, & Allen, 1992), and in the lexicon (Edwards & Lahey, 1996).

Effects of the mental lexicon on speech perception

The "lexical effect" is a tendency to perceive speech signals as real words. Two types of studies have examined lexical effects in adults: Lexical decision tasks in which tokens of word-nonword and nonword-word continua are mixed and presented randomly (Connine & Clifton, 1987; Fox, 1984; Ganong, 1980; McQueen, 1991), and identification tasks in which the tokens of each continuum are presented separately (Burton, Baum, & Blumstein, 1989). In both types of tasks, participants make a two-alternative forced choice response to individually presented stimuli along continua where the endpoints are a word and a nonword. In these studies, the lexical effect is demonstrated when the absolute auditory/phonetic boundary moves away from the end of the continuum that is a word, thus a shift in phonetic boundary occurs depending on which endpoint represents the word exemplar. The relative number of word versus nonword responses for ambiguous tokens indicates the influence of the mental lexicon in the selection process. Stored lexical representations therefore bias responses. Several studies have examined this effect with mixed results.

A classic lexical decision study with adults demonstrated the influence of the mental lexicon by using groups of CVCs in which words and non-words were the paired endpoints (e.g., DICE-TICE; DYPE-TYPE) along voice onset time (VOT) continua (Ganong, 1980). Participants listened to randomly presented CVC tokens and indicated by writing whether the initial sound was "D" or "T" When uncertain, their perceptions were guided by lexical knowledge leading to over-identification of tokens as instances of the word. The phonetic boundary shifted away from the endpoint that was the word (e.g., DASH was more likely than TASH and TUFT was more likely than DUFT, etc.). At the endpoints, where stimulus ambiguity was diminished, subjects were more likely to identify tokens as nonwords and words based on auditory-phonetic information. The lexical effect (i.e., a bias toward perceiving a real word) occurred when the phonological composition of the stimulus token was uncertain. When the phonological composition was certain, the auditory/acoustic information determined the selection (i.e., endpoint stimuli for words and nonwords are perceived according to the actual categorical characterization of the segments contained in the stimuli).

The lexical effect has been demonstrated in other studies that examined initial consonant transitions (Fox, 1984), and VOT continua (Connine & Clifton, 1987). Other studies examined the effect in more- and less natural stimuli. Burton, Baum, & Blumstein (1989) compared the identification of two separate 12-step VOT continua (i.e., DUKE-TUKE and DOOT-TOOT). More natural (i.e., amplitude of the burst and aspiration were covaried with VOT) and less natural (i.e., only VOT was varied) stimuli were compared. The purpose was to determine if covarying other voicing cues would influence categorization. A lexical effect occurred when the stimuli varied by VOT only (i.e., were of less natural quality); and not when other features covaried. A lexical decision task in which a final consonant continuum was used (e.g., FISH-FISS vs. KISH-KISS) yielded similar results (McQueen, 1991) for natural stimuli and degraded stimuli (i.e., low pass filtering). The degraded stimuli produced a lexical effect, whereas the natural stimuli did not (McQueen, 1991). These findings suggest that for adults, the lexical effect occurs when insufficient or conflicting acoustic information interferes sufficiently with the signal such that determination of the composition of the message is compromised. Each variation or modification of the signal reduces natural redundancy that allows listeners to segment and recognize the token. For adults, reduced redundancy may interfere with recognition less than it does for children. It is also possible that children with TLD may require less redundancy than children with SLI.

Children acquire and refine their lexicons despite variable input. They are able to acquire information about the phonological composition of words by attending to the available relevant cues despite absent or distorted cues. They achieve adult-like language skills with relative ease. It is likely that this occurs as a result of interactive relationships among perceptual and linguistic processes that are called upon during listening tasks. Children with SLI appear to be at a disadvantage in this endeavor. The processing deficits they demonstrate interfere with accurate segmental identification. Although many cues are available, children with SLI may have restricted access to them. Children with SLI may use some temporal cues more successfully than others, and they may use alternative strategies to acquire their lexicons.

Although it is likely that the word bias effect develops in childhood, this phenomenon has not as yet been examined developmentally. It is unclear whether there is a word bias effect for continua in which the duration of the vowel cues the perception of the voicing characteristic of the final consonant. It is unknown if an identification paradigm will demonstrate the word bias effect in children.

Purpose

The purpose of the current study was to examine the relationship between speech perception and lexical knowledge in children with SLI. To accomplish this, four continua were created with endpoint stimuli that were words and nonwords, and were presented to children with SLI and children with TLD using a traditional identification task. There were two objectives.

The first objective was to extend previous studies of perception in children with SLI by examining their use of a temporal speech cue not previously examined. The rationale was that if perception for brief temporal speech cues is impaired, then all brief temporal cues should be difficult for children with SLI to process. Specifically, this study examined whether small changes (i.e., 20ms step differences) in vowel duration are used as perceptual cues to the voicing characteristic of the final alveolar stop consonant in CVC stimuli. As previously noted, vowel duration is used as a cue by adults (Raphael, 1972) and typically developing children (Krause, 1982). Usually, short vowels are expected to cue a voiceless final consonant (e.g., -/t/ in FEET) whereas long vowels are expected to cue a voiced final consonant (e.g., -/d/ in FEED). Perception of a final segment was selected because of its relevance to some characteristic production errors that are common in children with SLI. Specifically, consonant deletions and omission of inflectional morphophonemes are often reported (Hodson & Paden, 1981). If children with SLI have deficits in the perception of this cue, they would have poor ability to identify minimally distinct final consonants in CVC syllables regardless of word- or nonword- status.

The second objective was to determine the influence of learned phonological representations on speech perception. The rationale was that as the mental lexicon develops, a system of phonological representations also develops. The current study explored how these representations are used in recognizing spoken words. This was accomplished by comparing the children's identification responses for different continua that varied in word status (i.e., word versus nonword). The continua were: word-word

(FEET— FEED), nonword-nonword (ZEET— ZEED), word-nonword (CHEAT — CHEED), and nonword-word (REET – READ).

Group responses comparing the word-word to the nonword-nonword continua helped to determine the extent to which children used already-existing representations in determining the segmental composition of new words. Group responses comparing the word-nonword to the nonword-word continua were used to determine if a lexical effect is present for children as has been shown in adults (Ganong, 1980). If children did demonstrate a preference for real words, it would verify that this effect develops during childhood. These findings would be helpful in discovering the role of stored lexical representations in recognizing spoken familiar words and in acquiring new vocabulary. In addition, findings of group differences in lexical effect, (i.e., SLI versus TLD) would aid in understanding the underlying cause of slow vocabulary growth in children with SLI.

Method

Participants

General criteria.

The criteria for inclusion as a child with SLI and as a child who is TLD in this study reflected the guidelines used in previous research (Stark and Tallal, 1981) combined with local community norms and current research practices (Plante, 1998). The selection method included a review of parent reported information (See Appendix B Parent questionnaire) about the children's academic, speech-language, medical, and socioeconomic histories. This was combined with standardized measures of language, hearing, and nonverbal intelligence (see below). Children were included from a range of socioeconomic backgrounds. All children in this study were monolingual and had no apparent history of physical, neurological, or emotional disorders.

Twenty-six children (6;6 to 9;9) participated in this study. All had volunteered as participants in child language research conducted at the Clinical Research Center for Communicative Disorders (CCRCD) at the Albert Einstein College of Medicine of Yeshiva University, Bronx, New York. All the children resided in the New York City metropolitan area and its suburbs of Westchester County and Long Island.

Thirteen of the children (six females and seven males) exhibited typical language development (TLD). The remaining thirteen children (three females and nine males) exhibited Specific Language Impairment (SLI). The subjects were age-matched in pairs between groups within three months (see Appendix A for CAs at the time of testing). One of the SLI children was subsequently dropped from the study because she could not complete the training portion of the experiment (see below). Therefore, the data from twelve SLI children are reported here.

Non-language inclusion criteria.

The children exhibited nonverbal-skills performance above the range of mental retardation (Plante, 1998) and within the normal range (i.e., a standard score of 70-115) on The Test of Nonverbal Intelligence - 3rd edition (TONI – 3; Brown, Sherbenou, & Johnsen, 1997). All the children had normal hearing on the day of language testing. Specifically they passed a pure tone screening (American Speech-Language-Hearing-Association, 1990) at 20dB HL (ANSI, 1989) for the frequencies 500Hz, 1000Hz, and

2000Hz. They also had normal tympanograms defined by a peak compliance of .2 to 1.4 cm^3, a tympanic peak pressure between –150 to 100 daPa, and tympanogram gradient between 60 and 150 daPa (American National Standards Institute, 1989). In addition, all participants had intelligible conversational speech and no expressive phonological impairments.

Language criteria for group inclusion: SLI or TLD.

Children were grouped as SLI or TLD by an assessment protocol that included information from a parent report and by formal language testing. Criteria for inclusion as SLI were 1) a history of language impairment that had been identified and documented by a speech-language pathologist, and 2) poor scores on a standardized language test during formal assessment as administered at the CCRCD. In order to meet criteria for inclusion as SLI, children scored 85 (i.e., -1 SD) or lower on one or more composite scores (i.e., Receptive, Expressive, or Total Language) of the Clinical Evaluation of Language Fundamentals, Third Edition (CELF-3, Semel, E., Wiig, E., & Secord, W., 1995). This cutoff score was employed in order to avoid the exclusion of children with SLI (Brinton, Fujiki, & McKee, 1998, Catts, 1993; Cleave & Rice, 1997, Connell & Stone, 1992, Fazio, 1997, Leonard, McGregor, & Allen, 1992, Plante, 1998).

Children were identified as TLD if their parents reported age appropriate grade and reading levels, no history of speech or language impairments, and all composite standard scores for Receptive, Expressive, and Total Language within the typical range (85-115) on the CELF-3. Results of testing for individual children are included in Appendix A.

Analysis of variance for repeated measures and planned comparisons were used to examine standard score results. Significant between-group differences were found for the Receptive ($p < .001$), Expressive ($p < .001$), and Total Language ($p < .001$) composite scores of the CELF-3 (Semel, Wiig, & Secord, 1995). There were no between-group differences for chronological age or for the TONI-3, (Brown, Sherbenou, & Johnsen, 1997) (p's > .05) (Table1).

Table 1

Ages and standard scores for SLI and TLD groups: Means (standard deviations)

		CELF-3[a]			
	Age in months Mean (SD)	Receptive Language[a*]	Expressive Language[a*]	Total Language[a*]	TONI-3[b]
SLI (n = 12)	92.25 (11.9)	88.3 (9.3)	76.0 (9.2)	80.9 (7.8)	92.2 (10.0)
TLD (n = 13)	92.31 (12.2)	105.4 (8.5)	103.1 (8.7)	103.9 (8.0)	99.3 (10.1)

[a]Semel, Wiig, & Secord (1995) [b]Brown, Sherbenou, & Johnsen, (1997)

*$p < .01$

Socio-economic status.

The children in both groups had diverse racial and socioeconomic backgrounds The SLI group included four white (33%), six black (50%), one Hispanic (8%), and one of unknown (i.e., not reported: 8%) ethnic group. The TLD group included seven white (53%), four black (31%), one American Indian or Alaskan native (8%), and one of unknown (i.e., not reported: 8%) ethnic group. The parents' educational and occupational experiences varied within the groups. The lowest level of education for mothers and fathers in both groups was completion of 10th grade. The highest level of education for mothers and fathers for both groups was graduate level. For five children in each group, both parents were employed. In the TLD group, seven mothers were homemakers. In the SLI group, three mothers were homemakers. Four fathers in the TLD group and three in the SLI group did not provide occupational information. Two fathers in the SLI group were disabled. In both groups, occupations varied from unskilled workers to administrators according to criteria established by Hollingshead (1975) (See Appendix A)

Experimental Perception Task

Stimuli.

Four Consonant-Vowel-Consonant (CVC) minimal pairs with members differing in the voicing characteristic of the final consonant were used as endpoints in the creation of four 13-step continua. Each pair represented one of four continua. Each of the four continua constituted a different lexical condition: a) word – word (FEET – FEED); b) nonword – nonword (ZEET – ZEED); c) word – nonword (CHEAT – CHEED), and d) nonword – word (REET – READ). These words and nonwords were selected because they contain initial consonants that differ by at least two distinctive features, and they contain the same "steady state" vowel. The real words had high frequency of occurrence and were likely to be familiar to children (see below), and the nonwords were phonotactically appropriate to English. Along each continuum, vowel duration, the independent variable intended to serve as the perceptual cue to the voicing characteristic of the final consonant, varied in 20ms steps (see below)

Word frequency.

Each stimulus word was examined for its frequency of occurrence in English Three word frequency measures for written language in adults (Carroll, Davies, & Richman, 1971) and one measure of oral language in children (Moe, Hopkins & Rush, 1982) are summarized in Table 2. For both children and adults, READ is most frequently used, followed by FEET and FEED CHEAT is much less frequent In spite of the differences in frequency, these words were selected because they had the same vowel and easily distinguishable consonants. The large difference in frequency of occurrence across the words could have been a confounding variable This possibility will be considered below

Table 2

Word familiarity ratings for real word stimuli for adults and children

	Adults		Children	
Stimulus word	F [a,e]	U [b,e]	Grade 3 [c,e]	Grade 1 [d,f]
READ	3057	561 18	604	103
FEET	2545	463 34	380	77
FEED	372	65 633	88	27
CHEAT	12	1 0856	1	3

[a]Frequency per million words in written texts. [b]Frequency per million adjusted for text type. [c]Frequency per million in third grade level books. [d]Frequency per 286,108 word oral language sample [e] Carroll et al., (1971) [f] Moe, Hopkins & Rush (1982)

Experimental stimuli

The stimuli were created by first measuring mean durations of four natural productions of each CVC (i.e., CHEAT, CHEAD, FEET, FEED, REAT, READ, ZEET, ZEED) spoken by the researcher. The productions were recorded directly into a personal computer using a digital audio editor-recorder-mixer software, Cool Edit Pro (Syntrillium, 1997). This same software was used to edit the stimuli.

For all stimulus tokens, segment durations were guided by the calculations of overall means from the natural utterances reported in Table 3. The initial consonants (C1), (/r/, /f/, /z/, /tʃ/), were extracted from the natural productions and each was edited to 120ms. The stopgaps that followed the vowel were transformed to silence in order to remove the aspiration cues and edited to 85ms. The final consonants (C2) were created from the first 15ms of the burst of natural final /t/. This portion of the signal provided the cue that C2 was a stop consonant.

Table 3

Mean durations (SD) in ms of initial consonants (C1), steady states (i), and stop gaps for words and nonwords.

Stimulus	C1	/i/ (SS)	Stopgap
FEET	88 (15)	133 (26)	121 (8)
FEED	85 (17)	318 (109)	68 (10)
CHEAT	155 (31)	148 (28)	102 (9)
CHEAD	138 (15)	306 (76)	69 (10)
REAT	95 (44)	116 (23)	98 (13)
READ	85 (30)	231 (18)	57 (6)
ZEET	165 (<1)	188 (15)	100 (8)
ZEED	145 (<1)	283 (8)	70 (<1)
Overall M (SD)	121 (42)	213 (32)	86 (6)
Range	50-200	116-318	50-144
Final edits	120	110-350	85

The natural productions contained a descending transition following the "steady state" of the vowel before the voiced final alveolar stop. The stimuli were edited to remove these cues so that the only cue available in each continuum was the vowel duration.

Vowel durations for the experimental tokens ranged from 110ms to 350ms in 20ms steps. These durations were based on calculations (i.e., 116ms – 318 ms; Table 3) from natural speech but were extended somewhat beyond the natural range. The vowel portions of all tokens were created from one natural 270ms /i/ file that was expanded or reduced appropriately. Thirteen steady states varying by 20ms were created (i.e., 110ms, 130ms, 150ms, 170ms, 190ms, 210ms, 230ms, 250ms, 270ms, 290ms, 310ms, 330ms, 350ms) to which a stopgap (85ms) and C2 (15ms) were added These 13 WAV files were each copied three more times so that there were four identical sets each containing 13 VC tokens The result was four 12-step stimulus continua varying in vowel duration

Stimulus intensity variations were controlled and noise was extracted The amplitudes of the stimuli were measured using the statistics function of the WAV editing software (Syntrillium, 1997) The Dynamic Processing function was used to maintain peak amplitudes of -2 68 dB for all vowels without frequency clipping. The editing software was also used to filter background noise from each stimulus Calibration procedures included generating a continuous steady state /i/ (2000ms) at 80dB SPL (C scale) This output was measured when delivered through the test earphones (Radio Shack NOVA-37 In-Ear Stereo Headphones, 100 – 20,000 Hz response range). It was calibrated with the Audioscan RM500 in sound-level meter mode using the probe tube microphone coupled to a real ear ($2cm^3$) coupler with insert earphones in place The mean overall segment amplitude of a 110ms vowel was 58dBSPL and the mean amplitude of a 350ms vowel was 68 dBSPL. These differences in dBSPL are natural correlates to durational differences and occurred similarly in all 4 continua.

Picture representations.

Computer generated color picture referents (Boardmaker, Mayer-Johnson, 1998) for each word and nonword were printed on index cards. The referents for the nonwords were abstract figures not associated with any real words (See Appendix C). A small red or blue smiley face sticker corresponded to stickers placed on the computer keys. During the experiment, one pair of pictures was mounted with Velcro on a cardboard cover that obscured the computer screen. The individual pictures of each pair were placed above their corresponding keys.

The experiment: training and identification tasks.

The experiment was preceded by a pre-training phase and a training phase. The pre-training phase included an informal introduction to the stimuli and the task. The training phase included a criterion-based computerized task. The experiment involved an identification task that was administered for each continuum separately. The computerized tasks were created using a software application, E-prime, that generated the tasks and recorded and processed the data (Psychology Software Tools, Inc., 1999). Data were recorded from key presses (key press "1" or "0") for each stimulus presented. The experiment was administered on a PC laptop.

During the pre-training, the examiner introduced the pictures of all the stimulus words (READ, FEET, FEED, CHEAT) for the child to identify. The child was asked to point to the pictures as the examiner labeled them. The child was encouraged to say each word, define or describe each word, and use each in a sentence. By this procedure, the examiner was able to determine that the child could associate each picture with the spoken word by pointing. The examiner then introduced all the pictures that represented the nonwords (CHEAD, REAT, ZEET, ZEED). The child was again asked to say each nonword, describe the pictures, and point to each as the examiner said them.

The examiner then presented the pictures two at a time in pairs (i.e., CHEAD was paired with CHEAT, REAT was paired with READ, FEET with FEED, and ZEET with ZEED). The examiner asked the child to point to each as it was named. The child was encouraged to point as quickly as possible. The criterion for proceeding to the next level of verbal pre-training was 3/3 consecutive correct pointing responses to each stimulus for each pair.

The examiner then directed the child's attention to the colored stickers on the pictures and to the corresponding stickers on the computer keys. The child was instructed to point to the red sticker on the stimulus card and then to the red sticker on the computer key. This was repeated for the blue stickers. The examiner explained that the child was to press the key that corresponded to the stimulus picture. The examiner then covered the laptop computer screen with one pair so that its picture was above its corresponding key. The child was instructed to press the associated key when the stimulus was heard. The child was reminded to press the key as quickly as possible. The examiner then orally produced each stimulus within one pair. The criterion for proceeding to the computer phase of the training was 3/3 consecutive correct key press responses. All children tested reached criterion on all aspects of the verbal pre-training.

During the computer-training phase, the child wore earphones and listened for each token. The child was told which pair of CVCs would be presented, and the associated pictures were affixed to the laptop screen. The child was reminded again to quickly press the key with the red or blue smiley face that corresponded to the words or nonwords heard. Each auditory stimulus was one of the paired endpoints (i.e., the stimulus with the 110ms vowel duration and the stimulus with the 350ms vowel duration) of each condition (i.e., word-word, nonword-nonword, word-nonword, nonword-word). They were presented randomly in blocks of twelve trials each with a 5 second response interval. The child received immediate verbal feedback from the examiner as to the correctness of each response. To begin the identification task for each linguistic condition, the child was required to respond accurately to 10/12 trials, which represented above-chance correct responses ($p < .016$) in one block. At the end of each training block, the child was given verbal feedback about total performance (e.g., "You got them all right." "You missed one.") The practice was repeated for each condition a maximum of seven times. Each block lasted approximately one minute. Computer training for each condition lasted four to seven minutes depending on how many blocks were required to reach criterion. After a child reached criterion, the identification task for the associated condition was initiated. The child was instructed to respond as quickly as possible when a word was heard and to "guess" quickly if unsure.

Each continuum was presented in three blocks of 26 trials each including two repetitions of each of the 13 stimuli (i.e., 13 vowel durations). The order of the stimuli was randomized. There was a maximum response latency of 5 seconds per trial. Each block was approximately 3.5 minutes in duration. There were 78 trials per pair (i.e., 26 trials per block X 3 blocks = 78 trials).

The presentation order of the continua was varied randomly across children (e.g., seven children received the word-word continuum first, five children received the word-nonword condition first, six children heard nonword-word first, and seven heard the word-nonword continuum first; each received a different order of continua thereafter). There were two versions of the experiment with key press responses counterbalanced across children for right and left side. In Version 1, all stimuli with final /t/ were associated with Key "1" (i.e., left side of keyboard) and all stimuli with final /d/ with Key "0" (i.e., right side of keyboard), in Version 2 the key associations were reversed. Half of the children in each group received Version 1 and half received Version 2. Children were given breaks, snacks, and small gifts between blocks as needed to maintain motivation. Total time to administer the training and the four identification tasks was approximately 1.5 hours.

Results

The results reported below are analyses of the training task and several relationships between speech perception and lexical knowledge comparing children with SLI to their same-age TLD peers. The computerized training task was examined by administering t-tests for independent samples to determine if children with SLI used more training blocks to reach criteria. The four identification continua were examined by using observational data and linear regression analyses. The purposes of the analyses were to 1) determine if children use vowel duration as a perceptual cue to the voicing characteristic of the final consonant and if the groups differed in the use of this cue, 2) determine if children demonstrate lexical effects and if the groups differed in the use of word knowledge. The responses of children with SLI and TLD were compared for observed and predicted (based on linear regression analysis) category boundaries, areas of certainty and uncertainty, and overall slopes of the identification function.

Computerized training

To determine if children with SLI required more training than children with TLD, the number of training blocks needed to meet criterion (i.e., 10 of 12 trials in one block, p = .016) were compared. For both groups, the training blocks ranged from four (i.e., 48 trials) to seven (i.e., 84 trials) for any one continuum. One child, who was included in the SLI group had physical difficulty pressing the response buttons. Despite training and repeated encouragement, she never pressed the keys with sufficient pressure for responses to be recorded by the computer. After five repetitions of one training block, she expressed frustration and refused to continue, and was excluded from the study. All other children completed the training and all four lexical conditions of the experimental task. There were no between-group differences (t [13] p's > .05) for three of four stimulus conditions (i.e., word-word, nonword-word, and word-nonword pairs). For the nonword-nonword pair, the SLI group required more training blocks (M_{TLD}=4.08, SD_{TLD} = .28; M_{SLI}=4.58, SD_{SLI} = .79, t [23] = .9930, p < .05) than the TLD group (Appendix D). However, the between-group difference was less than one block. Children with SLI learned the task and associated the acoustic properties of the endpoint stimuli with the appropriate key press at rates that were similar to the children with TLD.

Identification response analyses

Observed and predicted category boundaries and areas of certainty and uncertainty, and best-fit slopes were compared between groups and across continua. Category boundary was defined as the first and shortest vowel duration along each continuum at which the group mean response was equal to or crossed the 50% point. Area of uncertainty was defined as a vowel duration range in which group mean responses were at the level of chance (binomial distribution $p > .05$). This was less than 80% and greater than 20% identification responses for a given vowel duration. The area of certainty was the vowel duration range in which group mean responses were greater than 80% and less than 20%. This was expected to occur at the endpoints of each continuum. Comparisons between groups were made by observational analyses (Figures 1-6, Table 5), t- tests for independent samples (Table 4) and by t- tests comparing simple linear regression results (Table 6, Table 7, Appendix G).

Figures 1 – 4 depict the results of the TLD and SLI identification experiment for each of the four continua. Each figure shows the actual mean response slope and the best-fit slope. Figure 1 shows the identification slopes for the word-word continuum (FEET-FEED), Figure 2 for the nonword-nonword continuum (ZEET-ZEED), Figure 3 for the word-nonword continuum (CHEAT-CHEAD), and Figure 4 for the nonword-word continuum (REAT-READ). Each point on each identification slope represents the mean percent of -t responses at the indicated vowel duration. For example, for the FEET-FEED continuum (Figure 1) each point represents the mean percent of FEET responses for each group at each vowel duration. for ZEET-ZEED (Figure 2) each point represent the mean percent ZEET responses for each group.

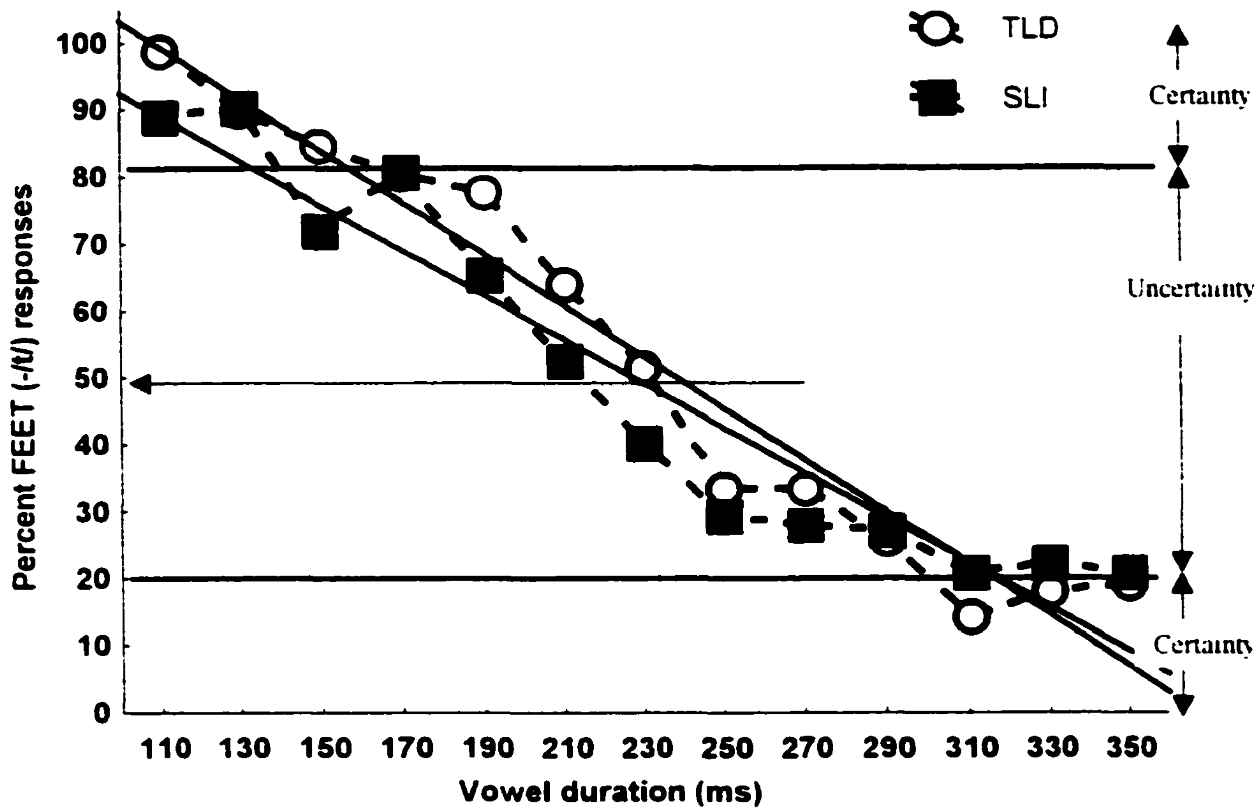


Figure 1. Mean identification responses (dotted lines) for FEET-FEED continuum in percent FEET comparing SLI and TLD with best-fit lines (continuous straight lines) and areas of certainty and uncertainty. The 50% FEET response point is indicated.

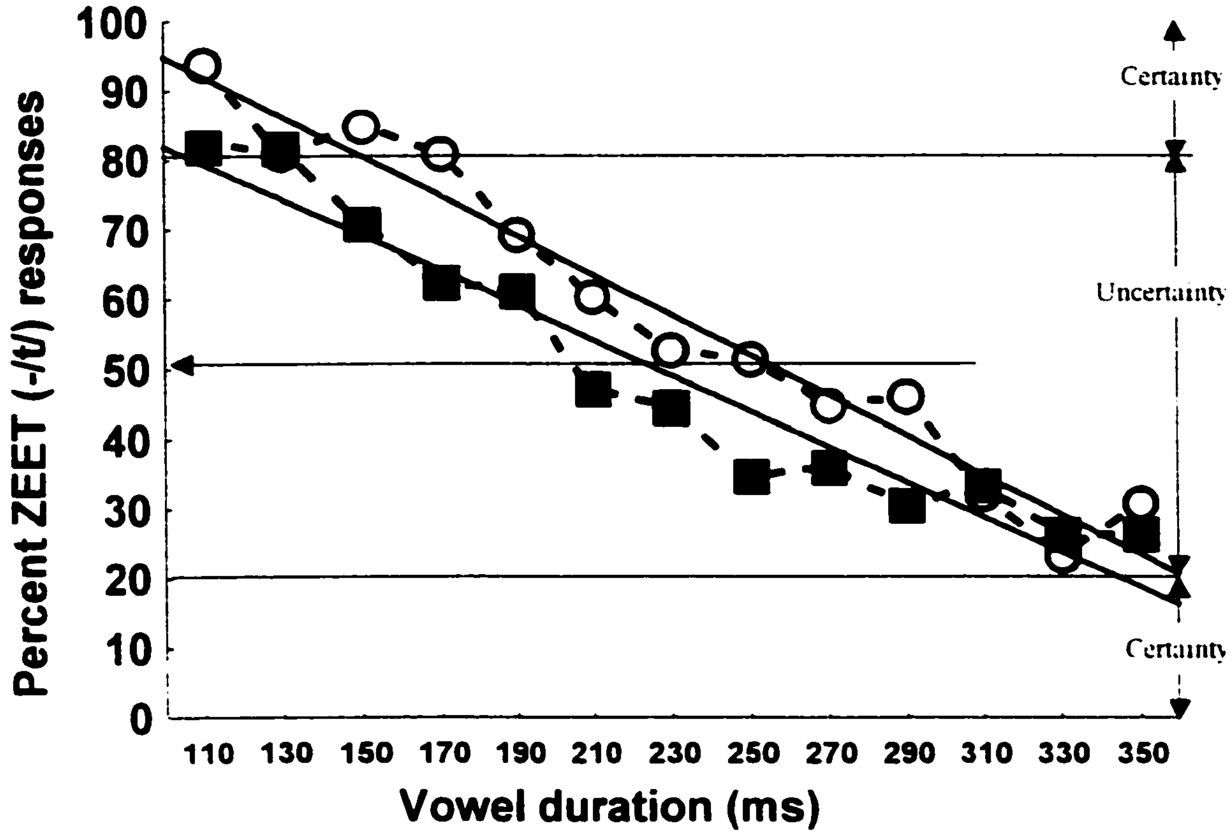


Figure 2 Mean identification responses (dotted lines) for ZEET-ZEED continuum in percent ZEET comparing SLI and TLD with best-fit lines (continuous straight lines) and areas of certainty and uncertainty The 50% ZEET response point is indicated.

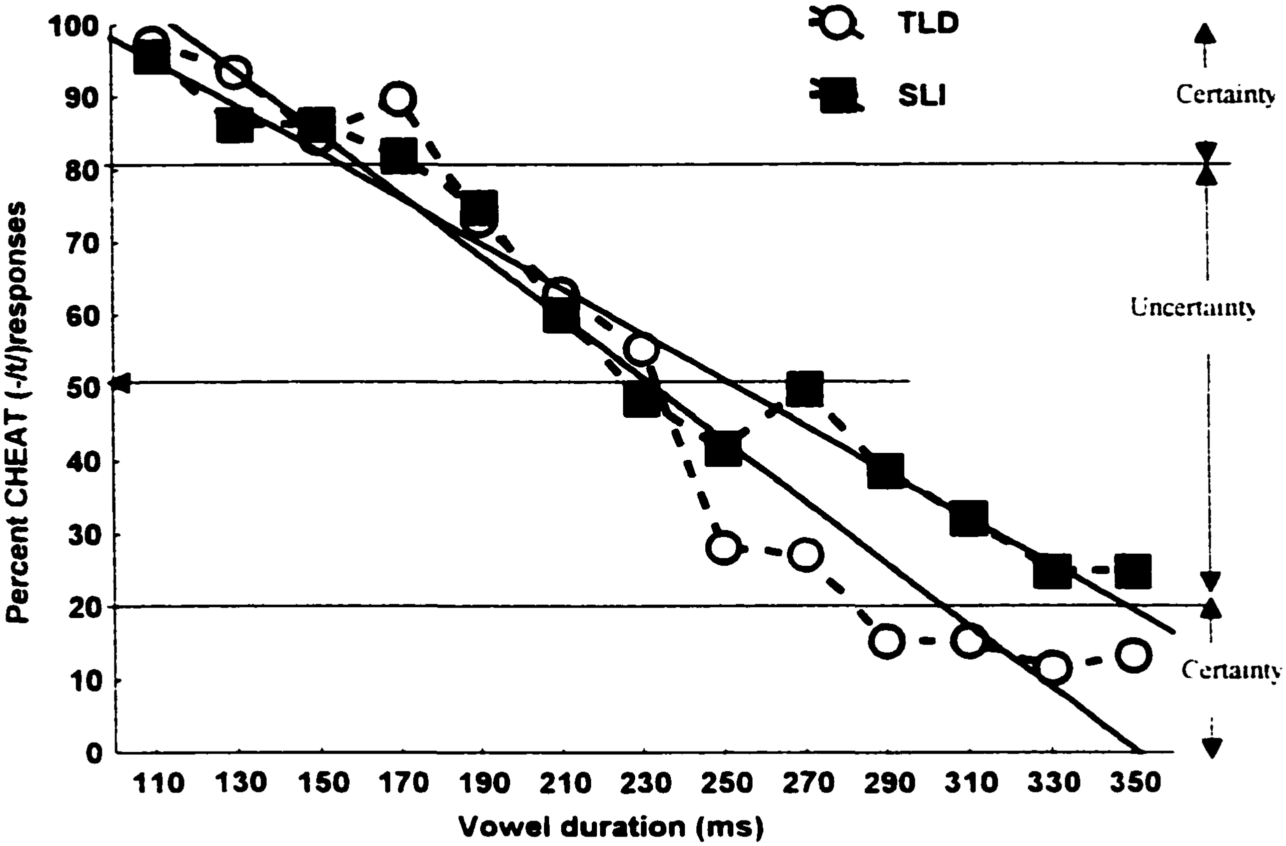


Figure 3 Mean identification responses (dotted lines) for CHEAT-CHEAD continuum in percent CHEAT comparing SLI and TLD with best-fit lines (continuous straight lines) and areas of certainty and uncertainty. The 50% CHEAT point is indicated

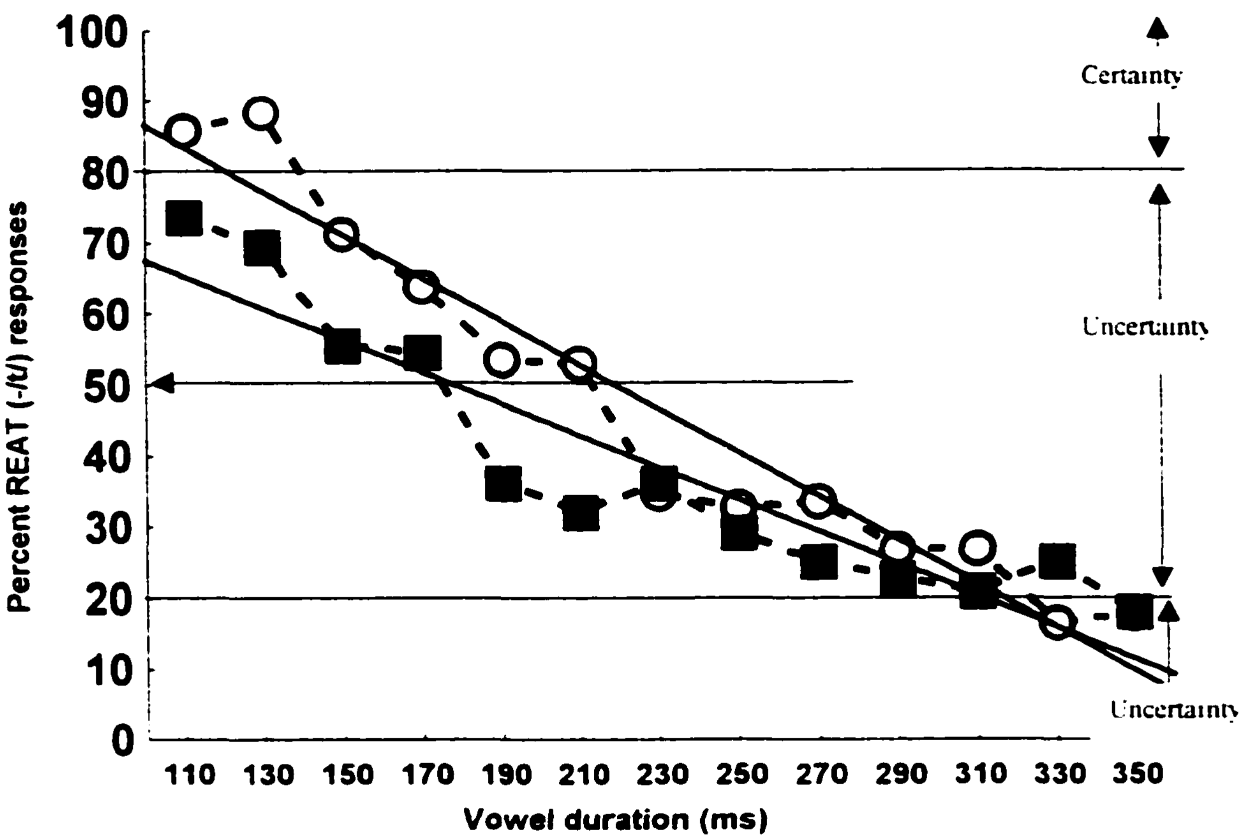


Figure 4. Mean identification responses (dotted lines) for REAT-READ continuum in percent REAT comparing SLI and TLD with best-fit lines (continuous straight lines) and areas of certainty and uncertainty. The 50% REAT point is indicated

Effect of vowel duration on perception of voicing characteristic of C2

To determine if vowel duration was used as a perceptual cue to final consonant voicing by children, their identification response slopes were examined for overall direction: Short vowels were expected to cue CV/t/, and therefore approach 100% CV/t/ responses; long vowels were expected to cue CV/d/, and therefore approach 0% CV/t/ responses. Figures 1-4 demonstrate that children in both groups used vowel duration as a cue to final consonant voicing in all four continua.

For three of the continua (word-word, nonword-nonword, and word-nonword) children in both groups demonstrated certainty for the endpoint tokens at the shortest vowel duration. For the fourth continuum (nonword-word) only the TLD group demonstrated certainty for tokens at the shortest vowel duration. For two of the continua (word-word and nonword-word), both groups demonstrated certainty for the longest vowel duration. For the nonword-nonword continuum neither group demonstrated certainty for tokens at the longest vowel duration. For the nonword-word continuum, the SLI group did not demonstrate response certainty for the longest vowel tokens whereas the TLD group did. These findings suggest that the short duration endpoint tokens cueing final /t/ were more salient than the long duration endpoint tokens cueing final -/d/ for all the children. This may be due to the omission of the downward transition in the stimuli that would normally occur as a secondary cue to presence of voicing in the final consonant.

To determine if the groups differed in the use of vowel duration as a cue, between-group comparisons for category boundaries and for uncertainty area ranges were made. Observed category boundary measurements for each child (Appendix E) were used to calculate the group mean boundary for each continuum. The group mean category boundaries were then compared by one-tailed t-tests for independent samples. The category boundaries of children with SLI were significantly shorter vowel durations than those of their TLD peers for the REAT-READ (nonword-word), FEET-FEED (word-word), and ZEET-ZEED (nonword-nonword) continua (p's < .05). These findings indicate a selection preference for -/d/ stimuli (i.e., FEED, READ, ZEED) in the areas of uncertainty by the children with SLI. There was no difference between groups for mean category boundary for CHEAT-CHEAD (word-nonword) (p = .09) (Table 4). Overall, these findings demonstrate that children with SLI had different phonological representations than their TLD peers as evidenced by category boundary shifts. These findings with temporal distinctions are similar to Sussman's (1993) findings with spectral distinctions (i.e., /ba/ vs / /da) Sussman also reported boundary shifts.

Range of observed uncertainty for each continuum was compared between groups. Table 4 summarizes the results of analyses by one-tailed t-tests for independent samples comparing the group mean ranges of uncertainty for each linguistic continuum. For two of the four continua, children with SLI demonstrated larger areas of uncertainty in identification responses than their TLD peers. The children with SLI demonstrated significantly larger areas of uncertainty for the nonword-word continuum (REAT-READ) and the word-word continuum (FEET-FEED) (p's < .05) (Table 4). No differences in range of uncertainty occurred between groups for the word-nonword continuum (CHEAT-CHEAD) and the nonword-nonword continuum (ZEET-ZEED) (p's > .05). The category boundary differences and the larger ranges of uncertainty for children with SLI suggest that although children with SLI use vowel duration as a cue to final consonant voicing, their category representations for final /t/ and final /d/ are different than for their TLD peers This difference is influenced by a preference to perceive final /d/ when uncertain

Table 4

Between-group comparisons of observed boundaries and ranges of uncertainty by stimulus continuum

	Segment boundary Mean (Standard Deviation)		One-tailed t-test results	
	TLD (N = 13)	SLI (N = 12)	*t* (23)	*p*
CHEAT-CHEAD	237 7 (32 2)	210 9 (42 5)	1 3282	09
REAT-READ	190 0 (46 2)	155 0 (43 6)	1 9782	03*
FEET-FEED	231 5 (40 4)	196 7 (53 5)	1 8316	04*
ZEET-ZEED	233 1 (52.2)	183 3 (36 5)	2 8073	006*
	Ranges of Areas of Uncertainty (ms) Means and (Standard Deviations)		One-tailed t-test results	
Condition	TLD	SLI	t (23)	p
CHEAT-CHEAD	71 7 (49.3)	104 0 (83 2)	1.2813	14
REAT-READ	110.8 (60.9)	163 3 (67 1)	4.2204	03*
FEET-FEED	72.3 (58.0)	130 0 (95 9)	3.3728	04*
ZEET-ZEED	129.2 (82.7)	161 7 (77 4)	1 0198	16

Simple linear regression was also applied to the best-fit data (Figures 1-4) and the predicted (as per linear regression) overall category boundaries were determined (Appendix G). The results of this analysis differed somewhat from the observational analysis. It confirmed that SLI category boundaries occurred at significantly shorter vowel durations than the TLD boundaries for two of the continua: nonword-nonword (ZEET-ZEED) and nonword-word (REAT-READ) (p's < .05). The SLI boundary was at significantly longer vowel duration for the word-nonword continuum (CHEAT-CHEAD) (observationally it did not differ from TLD results). Only the word-word continuum (FEET-FEED) did not demonstrate a difference in predicted between-group boundary (p > .05) (Appendix G and Figures 1-4). These findings further support a preference for /-d/ in the area of uncertainty for the nonword-nonword continuum, and a stronger lexical effect for READ and CHEAT for children with SLI (see below).

Effect of word knowledge on perception of vowel duration

To examine the effects of word knowledge on perception of vowel duration as a cue, category boundaries of the four continua were compared. The rationale was that boundaries would be affected by relative status of the CVCs in the continuum. The word-word and the nonword-nonword continua were expected to have similar category boundaries because the endpoints were equally weighted. The word-nonword and the nonword-word continua were expected to demonstrate boundary differences that favored the real word. Therefore, the word-word and nonword-nonword continua were expected to have similar category boundaries falling between the word-nonword and the nonword-word continua. Figure 5 presents a bar graph representing the idealized category boundaries for the four continua. The X-axis represents vowel duration; the Y-axis plots the four predicted category boundaries. Figure 5 also presents the observed category boundaries based on means reported in Table 4. Figure 5 shows that the directions of category boundary are similar for the SLI and TLD groups.

To describe category boundary responses for each member of each group, the observed boundaries for each child (Appendix E) were graphed (Figure 6). Each child's category boundaries bar graph (Figure 6) was rated for its similarity to the idealized bar graph in Figure 5. The rating scores were assigned without reference to actual vowel duration values. A scale of 0 – 4 was used. A rating of "0" was assigned to those bar graphs that did not reflect the idealized graph, "1" was assigned to those that demonstrated equal boundaries for the FEET-FEED and ZEET-ZEED continua, "2" was assigned to those that demonstrated a shorter vowel duration boundary for REAT-READ than for CHEAT-CHEAD, "3" was assigned to those that demonstrated shortest boundary for REAT-READ and longest boundary for CHEAT-CHEAD with FEET-FEED and ZEET-ZEED boundaries between, but not necessarily equal to each other, "4" was assigned to those configurations that matched the idealized version (REAT-READ shortest vowel duration followed by FEET-FEED and ZEET-ZEED with equal vowel durations, followed by CHEAT-CHEAD with longest vowel duration).

Table 5 summarizes the results. Nine children in the TLD group and eight children in the SLI group demonstrated category boundary shifts that are similar or identical (ratings of 3 or 4) to the idealized graph. Four children in each group did not display the predicted boundary relationships. Although most individuals within each group produced category boundary relationships that reflected the idealized version depicted in Figure 5, a few children in both groups (TLD and SLI) produced boundary relationships that differed.

Taken together, the analyses reveal that although children with SLI perceived small differences in vowel durations, their use of this as a cue to C2 voicing characteristic in CVCs differed from their TLD peers. Although children with SLI shifted category boundaries for the four continua in the same directions as their TLD peers, their boundaries were at shorter vowel durations for three of the four continua. In addition, children with SLI demonstrated less response certainty overall, a preference for CV/d/ in three of the continua in the areas of uncertainty, and a larger range of uncertainty for two of the four continua.

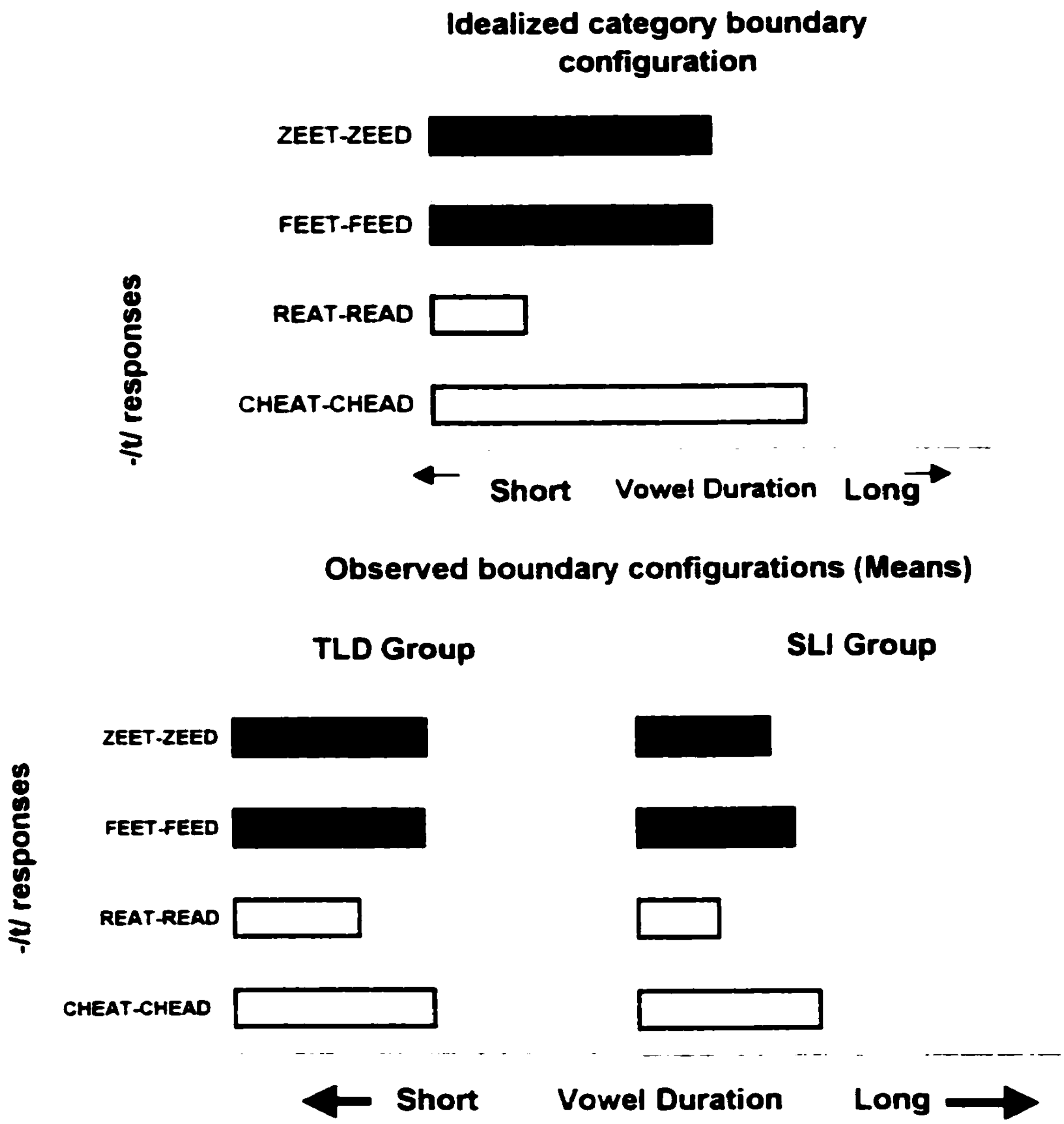


Figure 5 Category boundaries for all conditions: Examination of idealized and observed group boundary configurations

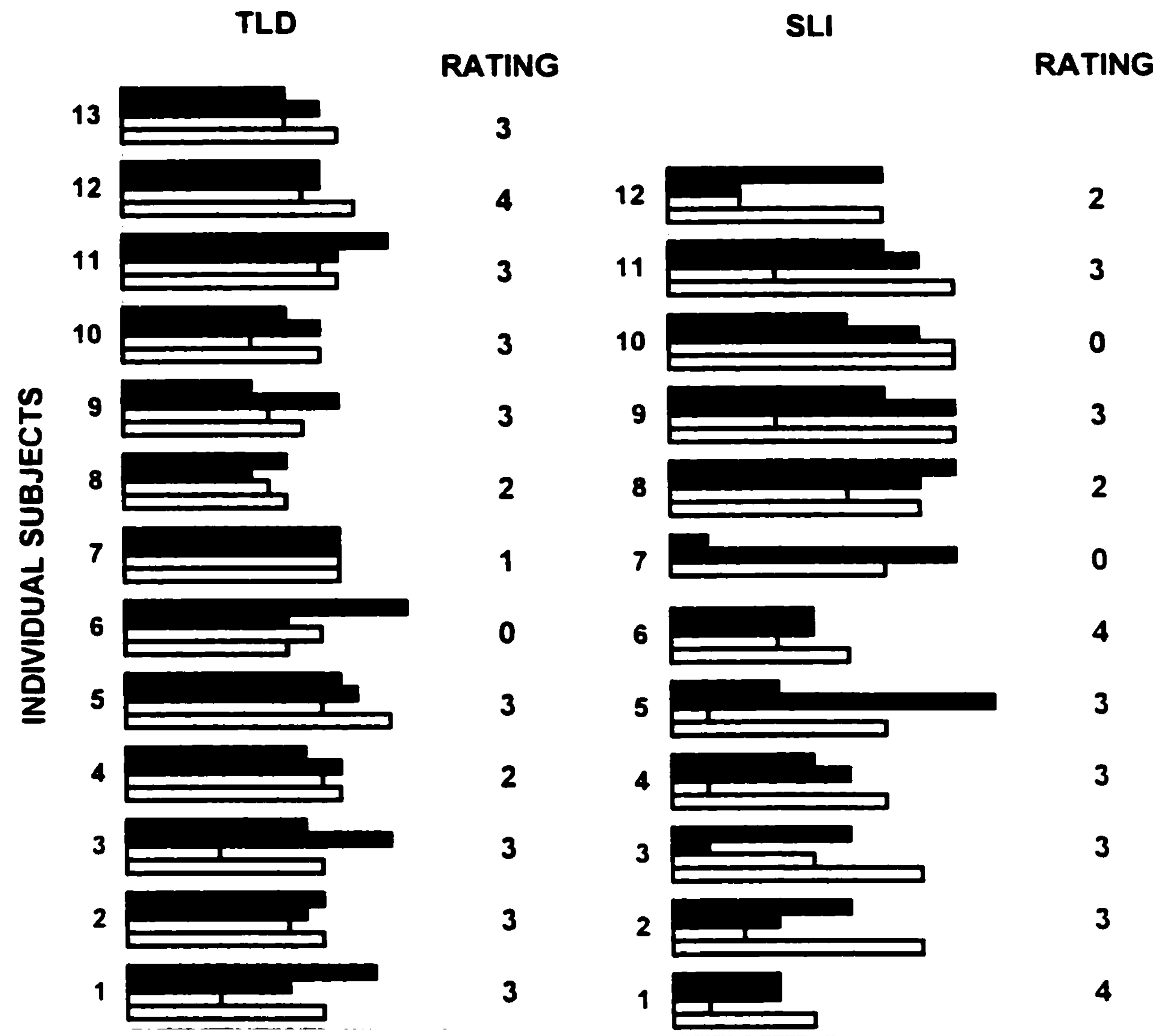


Figure 6 Individual child category boundaries by group, and configuration rating scores for each child.

Score key for Figure 6
0 Pattern does not reflect idealized comparisons
1 FEET-FEED = ZEET-ZEED
2 REAT-READ < CHEAT-CHEAD
3 REAT-READ < (FEET-FEED and ZEET-ZEED) < CHEAT-CHEAD
4 REAT-READ < (FEET-FEED = ZEET-ZEED) < CHEAT-CHEAD

Table 5

*Boundary configuration scores by group***

	Number of children per group demonstrating each boundary configuration				
Rating	0	1	2	3	4
TLD (N = 13)	1	1	2	8	1
SLI (N = 12)	2	0	2	6	2

Score key for Table 5
0 = Pattern does not reflect idealized comparisons
1 = FEET-FEED = ZEET-ZEED
2 = REAT-READ < CHEAT-CHEAD
3 = REAT-READ < (FEET-FEED and ZEET-ZEED) < CHEAT-CHEAD
4 = REAT-READ < (FEET-FEED = ZEET-ZEED) < CHEAT-CHEAD

Comparing slopes

To compare response patterns between groups and between continua, slopes were analyzed by simple linear regression. In order to determine if linear regression is an appropriate mode of prediction, an ANOVA was performed to determine if group response means were differentiable. Results were significant for each continuum ($F_{CHEAT\text{-}CHEAD}[2] = 227.66$; $F_{FEET\text{-}FEED}[2] = 212.59$; $F_{REAT\text{-}READ}[2] = 120.23$; $F_{ZEET\text{-}ZEED}[2] = 140.48$; p's < .0001).

Linear regression was used to determine group differences in slopes focusing on overall slope (i.e., vowel durations 110-350ms) and areas of certainty and uncertainty for each continuum (Appendix G). Table 6 summarizes the t-tests and p- values for the effect of group on each linear regression for each continuum. The table displays the analyses for the total regression slope (vowel durations extending from 110-350ms). and the results for the areas of certainty and uncertainty To use the t- test, the vowel duration range had to begin and end with the same vowel durations for each group. Therefore, the vowel duration ranges for the TLD group for each continuum were used (Appendix G) Although the areas of certainty are different for the two groups, the TLD areas were assumed to represent the norm for the larger population to which SLI children were compared

The SLI children demonstrated less response certainty than the TLD children overall as indicated by generally flatter slopes in all but the FEET-FEED continuum There was no group difference for the word-word (FEET-FEED) continuum ($p > .05$), whereas there were differences for the word-nonword (CHEAT-CHEAD), nonword-word (REAT-READ), and nonword-nonword (ZEET-ZEED) continua (p's < .05) In the areas of uncertainty, there were no between-group differences in comparison of slopes for three of the four conditions Only the REAT-READ continuum demonstrated an effect of group In the areas of certainty, there were group differences apparent for CHEAT, CHEAD, ZEET, and FEET (p's < .05) (Table 6) The nonword-word continuum (REAT-READ) was more difficult for both groups of children as evidenced by large areas of uncertainty The areas of certainty were too limited for group comparisons

Table 6

t-tests and p values for group effect (TLD vs. SLI) on linear regression for each slope.

Lexical condition	Area	Range (ms)	t(1)	p
CHEAT-CHEAD	Total	110-350	2.23	0.0266*
	Certainty CHEAT	110-170	2.32	0.0226*
	Uncertainty	190-270	1.04	0.2983
	Certainty CHEAD	290-350	4.18	<.0001*
ZEET-ZEED	Total	110-350	3.24	0.0013*
	Certainty ZEET	110-170	4.44	<.0001*
	Uncertainty	190-350	1.60	0.1100*
REAT-READ	Total	110-350	3.03	0.0027*
	Uncertainty	130-330	2.86	0.0045*
FEET-FEED	Total	110-350	1.49	0.1366
	Certainty FEET	110-190	2.76	0.0067*
	Uncertainty	190-290	1.33	0.1863
	Certainty FEED	290-350	1.23	0.2231

* p values are significant < .05

Testing for lexical effects: Lexical effect is present in children

Lexical effects in adults have been described in word-nonword continua (Ganong, 1980) as shifts in the segment boundaries toward the nonword endpoint resulting in more tokens selected as words than nonwords. In the current study, both groups of children demonstrated lexical effects. This was evidenced by category boundaries that favored the real words CHEAT and READ for both groups (see Table 7). Within group analyses using one tailed t-tests comparing word-nonword versus nonword-word segment boundaries based on predicted values (Appendix G) revealed that both groups demonstrated significantly different boundaries for CHEAT-CHEAD vs. REAT-READ continua that favor the real word response (p's < .01), thus supporting a lexical effect. Analysis of the word-word (FEET-FEED) vs. nonword-nonword (ZEET-ZEED) boundaries revealed no significant difference for either group (p's > .05) (Table 7).

Table 7

Within group one-tailed t-tests comparing predicted segment boundaries for word-nonword versus nonword-word continua and word-word versus nonword-nonword continua.

	TLD		SLI	
	t (23)	p	t (23)	p
CHEAT-CHEAD versus REAT-READ	3.0368	.003*	3.7676	.001*
FEET-FEED versus ZEET-ZEED	.0710	.472	.7180	.24

The lexical effect is stronger in children with SLI

Differences in the strength of the lexical effect were determined by analyses of variance for main effects for real word (CHEAT and READ) responses on the nonword sides of the segment boundaries (i.e., CHEAD and REAT respectively). Children with

SLI to choose CHEAT (M_{TLD} = 16.6, M_{SLI} = 34.1) in the vowel durations of 270 -350ms more frequently than children with TLD (F [1, 23] = 3.80; $p < .06$), and children with SLI chose READ (M_{TLD} = 30.6, M_{SLI} = 46.5) more often than TLD (F [1, 23] = 5.27; $p < .03$) in the vowel durations of 110 - 210ms. Thus, children with SLI had a stronger word bias effect than children with TLD.

In summary, the results indicate that children with SLI used cues from neighboring vowel sounds to determine the identity of final consonants in words and nonwords. Specifically, they perceived vowel duration differences and used these differences as cues to the voicing characteristics of the final alveolar stops in CVCs. However, when their responses were compared to their TLD peers, it was evident that use of this cue differed. Analyses of both observed and predicted boundaries and slopes demonstrated differences. Although the category boundaries in the four continua for the children with SLI are distributed in the same way as their TLD peers, their boundaries are at shorter vowel durations for three of the four conditions. In addition, children with SLI demonstrated less response certainty overall, a preference for CV/d/ in three of the continua, and a larger range of uncertainty for two of the four continua. For the predicted word-word continuum, slopes of children with SLI were similar to their TLD peers. For all other continua their slopes were different.

Discussion

Children with SLI may have phonological misrepresentations that interfere with lexical acquisition and access (Edwards & Lahey, 1996; Gathercole & Baddeley, 1990). These misrepresentations have been attributed to atypical segmentation of utterances due to an auditory processing disorder. However, researchers do not agree on the nature of this auditory processing disorder. Two views of the auditory processing disorder were considered in the current study.

One view is that children with SLI have perceptual deficits on the acoustic-phonetic level specific to the temporal features of speech. In this view, children with SLI are unable to accurately discriminate brief or rapidly changing acoustic cues for consonants and vowels (Tallal, et al., 1993). Many of the studies supporting this view used the auditory repetition task (ART) (Stark & Tallal, 1981). The design of ART has been strongly criticized (Studdert-Kennedy et al., 1994, Bishop et al., 1997). Although it is indisputable that children with SLI responded more poorly than their TLD peers on the ART when stimuli contained brief or rapidly changing cues (Leonard, 1998), what was unknown was why they performed so poorly (Studdert-Kennedy et al. 1994). Specifically, the reported auditory processing deficits were based on children's failures to meet criteria on the subtests of the ART during which they were learning to associate an auditory stimulus with one or more button press responses. Children with SLI failed to meet criteria to proceed to more challenging subtests. Children who were TLD met the criteria. The poor responses of the children with SLI may have been due to task difficulty rather than due to the nature of the stimuli. Specifically, children with SLI may have had difficulty remembering which button to press. To avoid this confound, the current study used a criterion based training and a traditional two-alternative forced choice identification task. Stimulus pictures were used to facilitate association of button press with auditory stimulus. The training criterion had to be met before the experimental task was initiated. This allowed an examination of perceptual performance separately from learning the task. One child, who was identified as SLI, was unable to meet criterion during the training, because she did not press the computer keys with enough force. Her results could not be recorded and she was dropped from the study. Her performance was not reported as perception deficits, but rather as a failure to learn the task. Of course, she may have perceptual deficits, however, these could not be evaluated using the present paradigm.

In addition, most ART studies supporting deficits in auditory temporal processing have examined a few within-segment temporal features in initial and medial positions. Perception of segments in final position has not been studied. The current study examined vowel duration as a contextual temporal cue to the voicing characteristics of final alveolar stops in CVCs. Words and nonwords were used. The rationale was that if children with SLI had auditory processing deficits specific to temporal features of vowel duration, then identification of words and nonwords would be equally impaired. As will be discussed below, this was not the case.

A second view of the auditory processing disorder is that atypical phonological representations are caused by language processing deficits in children with SLI. In this view, segments are inaccurately categorized during auditory perception causing incorrect associations between speech signals and phonological representations (Sussman, 1993; Bishop et al., 1997; Gathercole & Baddeley, 1990). Children with SLI can discriminate fine acoustic differences but they have poor ability to use these differences as cues for segment identification. When segment identification is inaccurate, phonological misrepresentations develop. The studies supporting this view have used perceptual identification tasks with mono-syllables (Sussman, 1993), and verbal imitation tasks with mono- and multi- syllables, and word lists (Gathercole & Baddeley, 1990). No previous studies have combined perception of temporal features with word knowledge The current study explored the direct link between speech perception and phonological representations by using stimuli that were words and nonwords controlled for their temporal features.

In summary, the current investigation expanded the scope of previous speech perception research Children with SLI were compared to children with TLD on a task that examined vowel duration as a contextual temporal cue to the voicing characteristic of the final consonant in CVC words and nonwords A criterion based training task preceded the experiment Four continua were tested separately word-word (FEET-FEED), nonword-nonword (ZEET-ZEED), word-nonword (CHEAT-CHEAD), nonword-word (REAT-READ) Each continuum contained thirteen CVC tokens with vowel durations that varied in 20- millisecond steps. Tokens were presented randomly in a two-alternative forced choice identification task

The results of the training task and the identification task comparing children with SLI to children with TLD are summarized below The findings are reviewed regarding the use of vowel duration as a contextual temporal cue to the voicing characteristic of final alveolar stops in words and nonwords. Further, rationale are offered to reject the auditory temporal processing hypothesis, and support the language-processing deficit hypothesis as a reason for the phonological misrepresentation present in some children with SLI. In addition, the following discussion will summarize the findings regarding lexical effects: Both groups demonstrated a word bias for the word-nonword and nonword-word continua. The effect, however, was stronger for children with SLI. The implications of all these findings will be presented.

Children with SLI did not require more training than children who were TLD

Children with SLI performed similarly to the children with TLD in the number of training blocks needed to reach criteria for each continuum in order to proceed to the experiment. The children with SLI in this study were able to associate the key press response with the correct endpoint stimulus with the same amount of training as their TLD peers. Therefore, the children's performances on the identification task in the current study cannot be attributed to a slower learning curve for task.

Both SLI and TLD groups use vowel duration as a temporal cue

Both groups of children used vowel duration as a perceptual cue to the voicing characteristic of the final consonant in CVC words and nonwords. All response slopes demonstrated a relationship between vowel duration and the percent of final /t/ responses: shorter vowels tended to cue CV/t/ responses, whereas longer vowels tended to cue CV/d/ responses (Figures 1 – 4). The best-fit slopes for the word-word (FEET-FEED) continua did not differ between groups. Therefore, this temporal speech cue is comparably discriminable by children with SLI and TLD.

Vowel duration is a weak cue for children with SLI

Vowel duration was a weaker cue for children with SLI. This was evident in the analyses of three continua (nonword-nonword, nonword-word, word-nonword). As category boundaries differed, overall slopes were flatter, and areas of uncertainty were larger for children with SLI as compared to children who are TLD. These findings suggest that children with SLI had poorly developed vowel representations (Stark & Heinz, 1996) as compared to children with TLD despite adequate identification performance for temporal features of speech sounds as in the word-word continuum. Vowel duration therefore has limited value as a cue to final consonant voicing. Whether the vowel duration is long or short, children with SLI are less certain than their TLD peers as to the segment that is cued. It follows then that when children with SLI are exposed to new words, final consonants may be less well represented than for children with TLD. This could account for the final consonant deletions often reported as characteristic of children with language disorders.

Auditory temporal processing disorder account of SLI is not supported

The hypothesis that children with SLI have deficits in auditory temporal processing of brief signals (Tallal, et al., 1993, Tallal & Piercy, 1973a, 1973b, 1974, 1975, Tallal, 1976; Frumkin & Rapin, 1980) was not supported by this study. Previous studies have claimed that children with SLI responded more like their TLD peers when long duration cues were used (e.g., extended transition durations, longer VOTs, longer ISIs) (see Tallal, et al., 1993 for review). In the current study, this was not the case. Linear regression analysis (Table 6) revealed that children with SLI had flatter slopes than the children with TLD at the long vowel durations for two continua (i.e., CHEAD and READ). Flatter slopes indicate that children with SLI had poor response certainty for long vowels in one word and one nonword. Children with SLI responded with similar slopes at the long vowel durations for one word (i.e., FEED). Similar slopes indicate that children with SLI had response certainty comparable to TLD peers for long vowels for one word. Taken together, these finding do not support the view that long durations facilitate perception. The certainty of token identification for children with SLI was not related to duration.

Impaired language processing account in children with SLI is supported

The current study supports the view that children with SLI have impaired language processing that disrupts phonological representations This is evident when the responses between groups were compared across continua The word-word (i e., FEET-FEED) continuum was the only continuum among the four that demonstrated similar identification response slopes between the children with SLI and their TLD peers This suggests a greater salience of the vowel duration cue in more familiar words In this continuum, vowel duration combined with word knowledge allowed children with SLI to process tokens similarly to the children who are TLD The conclusion must be therefore, that for the children with SLI, the phonological representations for FEET and for FEED were accurately stored in long-term memory similarly to children with TLD; therefore, children with SLI were able to match the acoustic-phonetic (i.e., the vowel duration) characteristics of the tokens to the representations so as to distinguish between words.

All other continua contained at least one nonword. In these continua the nonwords had no semantic association (other than the stimulus picture). Identification of CVCs was based primarily on acoustic input. Acoustic input is too weak a cue for children with SLI to use without other higher-level cues (such as semantic associations). Segment compositions of new words are likely to be misrepresented. Once a word is well established, however, its phonological representation is available in long-term memory and retrievable for comparison to heard speech. These results imply that once the child with SLI recognizes that the new word is different from the old word (as in the establishment of FEET and FEED in the lexicon), its representation may be adjusted, reassigned semantically, and stored as a correct phonological representation.

A lexical effect was stronger in children with SLI

Children's perceptions of ambiguous tokens in word-nonword (CHEAT-CHEAD) and nonword-word (REAT-READ) pairs were influenced by linguistic knowledge as in adults (Ganong, 1980, Connine & Clifton, 1987, Fox, 1984). When uncertain, children in both groups tended to select a real word response rather than a nonword response. Children with SLI demonstrated a stronger lexical effect than their TLD peers. They relied more heavily on their already established lexicon, and selected real word responses more than children with TLD. These findings suggest that for minimally contrasted lexical items, children with SLI are more likely to assume that a CVC is a word with which they are familiar, rather than recognizing it as a new word they need to learn.

Implications of the findings

Children with SLI depend more on word knowledge to identify minimally distinct pairs than their TLD peers. The use of perceptual information (i.e., vowel duration as a cue to final consonant voicing) was more likely to be over-ridden by higher-level linguistic processes for children with SLI than for children with TLD. The strong influence of lexical knowledge combined with the differences in segment boundaries, may in part explain why children with SLI lag in vocabulary development. That is, for words that are well established in their mental lexicons, children with SLI are able to recognize speech stimuli that match or are similar to their lexical representations. However, because of their uncertainty about segment boundaries they tend to identify tokens of new words as exemplars of familiar words. It would follow then that children with SLI are more likely than children who are TLD to make improper assumptions about the relationship between words and meanings. That is, if a new word has been identified incorrectly in an utterance as a known word, the semantic association would be incorrect. Further research is needed to explore the direct effect of phonological misrepresentations on semantic development in children with SLI. The results of the current study would suggest that errors in the segmentation of newly learned words may severely alter the associations with their meanings, and to interfere with vocabulary/semantic development.

Little is known about how children develop accurate phonological representations. No studies to date have explored how children's lexical misrepresentations develop into accurate representations. The course of development of phonological representations for both children with SLI and TLD is unknown. Experiments focusing on the influences of phonotactic probability on word recognition in children with SLI may aid in this regard. A recent study examining phonotactic probability in word learning in typical children (Storkel, 2001) revealed that novel words were associated with meanings more rapidly when the words were created from highly frequent segment sequences. It is unknown what the relationship is between word learning and phonotactic probability in children with SLI. The current study was not designed to determine the effects of phonotactic probability. However, final /t/ is more frequent than final /d/ in English; perhaps this attribute contributed to the less accurate responses for the final /d/ endpoint stimuli, despite the preference for final /d/ responses in the areas of uncertainty. It would be important to determine which segments and segment combinations are most salient to children with SLI, and if these are correlated with phontactic probability.

Phonological representations occur as a result of innate and learned mental operations that allow the listener to code acoustic-phonetic speech signals into meaningful linguistic elements. The current study does not address the question as to whether the deficits occur as a result of some innate congenital aberration of the higher order cognitive-linguistic system, or of some faulty relationship between learning capacity and environmental input. Further research, prospective and longitudinal, is needed to determine the basis of the disorder that reveals itself as inaccurate assignment of speech signals to segment categories during the development of mental representations. In addition, further research is needed to determine how intervention provided to children with SLI might modify the development of phonological misrepresentations.

Summary

This study refutes the auditory temporal processing hypothesis, and supports the linguistic processing hypothesis as the area of deficit in children with SLI. Rather than a fundamental deficit in auditory perception for temporal features of speech, the difficulty children with SLI have appears to be related to the salience of duration as a speech cue relative to other information stored in higher-level mechanisms (Leonard et al., 1992). Children with SLI perceived vowel duration as a cue to final consonant voicing like their TLD peers in the word-word (i.e., FEET-FEED) continuum. However, their use of this cue was compromised as was evidenced in all other continua. It is likely that salience of other acoustic cues (e.g., spectral cues) is reduced as well (Sussman, 1993).

Children with SLI demonstrated a stronger lexical effect than their TLD peers. In the word-nonword continua, the perceptual cue (i.e., vowel duration) was over-ridden by higher-level cognitive-linguistic information stored in long-term memory (word knowledge). This finding suggests that when listening to speech, children with SLI are more likely to segment and then identify a novel word as if it were a familiar word; the semantic association will then be incorrect. This may be a cause of the slow vocabulary growth that is typical of children with SLI.

The current study provides a preliminary examination of the relationship between lower level perception and its interaction with higher-level language processing in children with SLI. However, the scope of this study is limited to one acoustic feature and a few isolated simple words and nonwords. Little is known about which acoustic features are most salient to children with and without language impairments. Exploration of a variety of contextual cues (e.g., temporal, spectral and intensity cues individually and in combination) is needed to identify which features children with and without language impairments extract from the speech signal as they develop phonological representations. In addition, further research is needed to determine how perception interacts with larger language units (e.g., multi-syllabic words, phrases, and sentences).

Appendix A

Group, chronological age (CA), gender, and standard scores, race, parent education and occupation for each child included in the study.

				CELF-3[a]			
Participant #	Group	CA	Gender	Receptive Language Score	Expressive Language Score	Total Language Score	TONI[b]
10	SLI	6,6	m	94	65	78	75
14	SLI	6:7	f	92	78	84	107
27	SLI	6.7	m	84	78	80	87
19	SLI	6.11	m	84	90	86	85
20	SLI	7.2	f	75	82	77	81
11	SLI	7.5	m	94	75	83	97
7	SLI	7.9	f	69	53	59	95
29	SLI	8.1	m	88	78	82	95
26	SLI	8.4	m	94	78	85	95
30	SLI	8.8	m	90	82	85	110
21	SLI	8.9	m	104	78	90	89
17	SLI	9.6	m	92	75	82	90
5	TLD	6.6	f	110	120	115	89
15	TLD	6.8	f	108	96	102	102
37	TLD	6.8	m	100	96	97	100
33	TLD	6.11	m	116	116	116	117
8	TLD	7.1	m	108	108	108	100
18	TLD	7.2	f	104	108	106	100
12	TLD	7.4	m	116	104	110	116
4	TLD	7:9	f	106	96	101	100
32	TLD	8.1	f	116	110	113	90
13	TLD	8.3	m	86	100	92	81
22	TLD	8:9	f	100	92	95	103
35	TLD	9:4	m	102	98	100	102
36	TLD	9:6	m	98	96	96	91

[a] Semel, Wiig, E., & Secord, W (1995) [b] Brown, Johnsen, Sherbenou, (1997)

Appendix A (continued)

Subject #	Group	CA	Race[1]	Mother's education[1]	Father's education[1]	Mother's occupation[1]	Father's occupation[1]
10	SLI	6.6	1	5	4	Teacher's Aide	Landscaper
14	SLI	6.7	2	6	4	Teacher	Financial Officer
27	SLI	6.7	2	3	5	Housewife	Disabled
19	SLI	6.11	1	6	6	News research	Photographer
20	SLI	7.2	6	5	4	Homemaker	Mail Clerk
11	SLI	7.5	2	4	4	Post Office Clerk	Not Provided
7	SLI	7.9	1	6	6	Not provided	Manager
29	SLI	8.1	3	3	6	Clerical Work	Electrician
26	SLI	8.4	2	3	5	Housewife	Disabled
30	SLI	8.8	1	7	7	Administrator	Director / Writer
21	SLI	8.9	2	5	3	Case Manager	Not Provided
17	SLI	9.6	2	6	6	Babysitting	None
5	TLD	6.6	1	4	5	Homemaker	Sales
15	TLD	6.8	2	5	4	Homemaker	NA
37	TLD	6.8	8	7	6	Coordinator	Senior Buyer
33	TLD	6.11	2	4	8	Admin. Assistant	Not Provided
8	TLD	7.1	1	7	7	Teacher	Banker VP
18	TLD	7.2	4	5	5	Homemaker	Technician
12	TLD	7.4	1	5	4	Homemaker	NYC Sanitation
4	TLD	7.9	1	5	5	Homemaker	Policeman
32	TLD	8.1	1	7	4	Audiologist	Manager
13	TLD	8.3	1	4	5	Homemaker	Chauffeur
22	TLD	8.9	2	5	3	Case Manager	Not Provided
35	TLD	9.4	1	5	7	Housewife	Administrator
36	TLD	9.6	2	5	8	None provided	Not Provided

Appendix A (continued)

Key for Race and Education

Code Number	Race	Education
1	White, not of Hispanic origin	Less than 7th grade
2	Black, not of Hispanic origin	Completed 9th grade
3	Hispanic	Complete 10th grade
4	American Indian or Alaskan Native	Completed high school
5	Asian or Pacific Islander	Partial College
6		College Graduate
7		Graduate Degree
8	None Provided	None Provided

Appendix B

Parent Questionnaire

Telephone Interview Form

Today's Date ____________________

Child's First Name ____________________ Child's Last Name ____________________

Child's Age _______________ Date of Birth ______________________________

Your Name ____

Your Relationship to the Child ______________________________________

Names of Parents/ Guardians _______________________________________

Child's Address ____

Home phone number ______________________________

Your work phone number _________________________

School ______________________________ Town __________________________

Grade ________________

How did you hear of the study newspaper____ poster______ friend_________

What is your child's primary language? English _________ Other ___________________

What language(s) are spoken at home? (check all that apply)

English______ Spanish_______ Italian_______ Other (specify) ______________

Who are the people your child frequently interacts with and what is their language?

______________________________ ______________________________

______________________________ ______________________________

In what languages are the programs your child watches on TV?

English _______Other (specify) _____________________

Is your child at appropriate grade level at school? Yes ________ No ________________

Any special classes? No ________ Yes ________(specify)_________________________

What specific academic activity is the child given in Special Ed or Resource Room

____

Any reading problems? No _______ Yes ______________

Did your child ever have to repeat a grade? No ______ Yes _______

Is your child's speech difficult to understand? No_____ Yes_____

Do you think your child exhibits a language delay? No_____ Yes _______

Has your child been evaluated by or worked with any of the following?

Ear Nose and Throat (ENT) Doctor_____ Neurologist_____Psychologist_____

Audiologist_____

Reading Specialist_____ Speech Language Pathologist_____

Other _________________________

Do you think your child hears well? Yes _____ No ____________________

Has your child ever had a hearing test in a facility other than school? No_____Yes ______

Where __________________________________

Does your child have any health problems ? No _____ Yes _______________________

Does your child have a history of frequent ear infections? No ____ Yes ______________

Does your child have any neurological problems (such as seizures. cerebral palsy)?

No _____ Yes ____

Has your child ever been hospitalized? No_____ Yes ___________________________

Is your child taking any medication? No_____ Yes ______________________________

Is there anything else you would like to tell us about your child? ____________________

____

Any additional comments

Appointment Information

Appointment for Speech and Language Core Evaluation ________________

Date ________________ Time __________________________________

Will call back ___________________________

Refused study after phone interview _________

Reasons for refusal ____

Parent Questionnaire (continued)
First visit interview form

You may have already answered some of these questions but it would be very helpful if you could complete the entire questionnaire. Please ask if you have any questions

INFORMATION PROVIDED IN THIS QUESTIONNAIRE WILL REMAIN CONFIDENTIAL.
INFORMATION ABOUT YOU AND YOUR CHILD WILL BE AVAILABLE ONLY TO THE DIRECTOR OF CLINICAL RESEARCH AT THE KENNEDY CENTER, COORDINATOR OF CLINICAL RESEARCH, AND THE RESEARCHER IN CHARGE OF YOUR CHILD'S PROJECT.

Today's Date ______________________

Child's Name ____
(First) (Middle) (Last)

Child's Date of Birth ______________________ Child's Sex: Male Female
(month) (day) (year)

Name of person completing questionnaire ______________________________
(First) (Middle) (Last)

Relationship to the child
(1) mother
(2) father
(3) relative legal guardian
(4) relative not legal guardian
(5) non-relative legal guardian

Address ____
(Street) (Apt) (City) (State) (Zip)

Home Telephone Number ( ) ______________

Alternate Telephone Number ( ) ____________________

If we have difficulty reaching you, or need to reach you, whom else may we contact?

______________________ Relationship to you: ______________________

Contact's telephone number: ( ) __________________

Address ____
(Street) (Apt.) (City) (State) (Zip)

Who else may we contact if we need to reach you?

____

Relationship to you ____________________

Contact's telephone number: ( ) __________________

Address ____
(Street) (Apt.) (City) (State) (Zip)

Race
(1) White, not of Hispanic Origin
(2) Black, not of Hispanic Origin
(3) Hispanic
(4) American Indian or Alaskan Native
(5) Asian or Pacific Islander
(6) Other

Mother's (primary caretaker's) Name ______________________________________
(first) (middle) (last)

Father's Name ____
(first) (middle) (last)

Sibling Name ______________________ DOB __________ Sex: Male Female

Sibling Name ______________________ DOB: __________ Sex: Male Female

Sibling Name ______________________ DOB __________ Sex: Male Female

Mother's Occupation (please be specific):

____

Father's Occupation (please be specific):

____

Level of Mother's Education: (1) Less than 7th grade
(2) Junior H.S. (9th grade)
(3) Partial H.S. (10th, 11th grade)
(4) H.S. graduate
(5) Partial college (at least 1 yr.)
(6) Standard college or university graduate
(7) Graduate professional training (graduate degree)

Level of Father's Education: (1) Less than 7th grade
(2) Junior H.S. (9th grade)
(3) Partial H.S. (10th, 11th grade)
(4) H.S. graduate
(5) Partial college (at least 1 yr.)
(6) Standard college or university graduate
(7) Graduate professional training (graduate degree)

Which parents live in household? (1) mother only
(2) father only
(3) both parents

Is child enrolled in a school program? Yes No

Name of Child's School, Preschool or Day Care Center:

____

Address of Child's School Preschool or Day Care Center:

____

Grade ___________ School District (number) _______________

School District (city/town) _________________

Does the child receive special education services? Yes No

If yes, please specify primary diagnosis:
(1) Gifted
(2) Slow learner, learning disabled
(3) Reading impaired
(4) Mentally retarded
(5) Speech/language impairment
(6) Hard of hearing or deaf
(7) Partially sighted or blind
(8) Orthopedically handicapped
(9) Emotionally disturbed
(10) Autism
(11) Central Auditory Processing Disorder

If applicable, please specify secondary diagnosis:

(1) Gifted
(2) Slow learner, learning disabled
(3) Reading impaired
(4) Mentally retarded
(5) Speech/language impairment
(6) Hard of hearing or deaf
(7) Partially sighted or blind
(8) Orthopedically handicapped
(9) Emotionally disturbed
(10) Autism
(11) Central Auditory Processing Disorder

Comments: ______________________________

Birth Status: (1) Premature
(2) Full Term

Birthweight: ____________ Birth Order (e.g. 1st born, 2nd born, etc.): ________

Gestational Age: ________ Number of days child was in hospital after birth: ________

Vision Status: (1) Normal without glasses
(2) Corrected by glasses to normal
(3) Vision impairment with glasses

If (3), please specify ______________________________

Hearing Status: (1) Normal
(2) Hearing-impaired

Does child wear a hearing aid? Yes No

Does child have a history of ear infections/earaches? Yes No

List any major
hospitalizations: ______________________________

List any major accidents: ______________________________

Currently taking medication? Yes No

If yes, medication is for: ______________________________

Has the child ever had seizures? Yes No
If yes, please explain:

____

Languages spoken at home:
(1) English only
(2) Mostly English, some Spanish
(3) Mostly Spanish, some English
(4) Spanish only
(5) Other

Other language spoken at home ________________________

Referral source:
(1) Doctor/physician
(2) Called directly by researcher
(3) School
(4) Advertisement in newspaper
(5) Friend/coworker
(6) Posted notice
(7) Other: ________________________

Are you willing to have your child participate again in this study? Yes No

Do you give permission to be contacted at a later time about your child's participation in another study? Yes No

Have siblings ever participated? Yes No

Do you give permission to be contacted at a later time about your child's sibling's participation in another study? Yes No

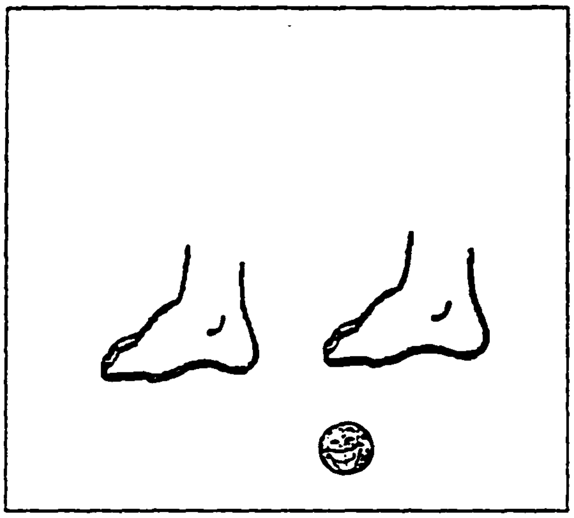
Handedness (complete only if the child is 2 years old or older)
(1) Left
(2) Right
(3) Ambidextrous (switches between left and right hand)

REVISED 6/13/2001

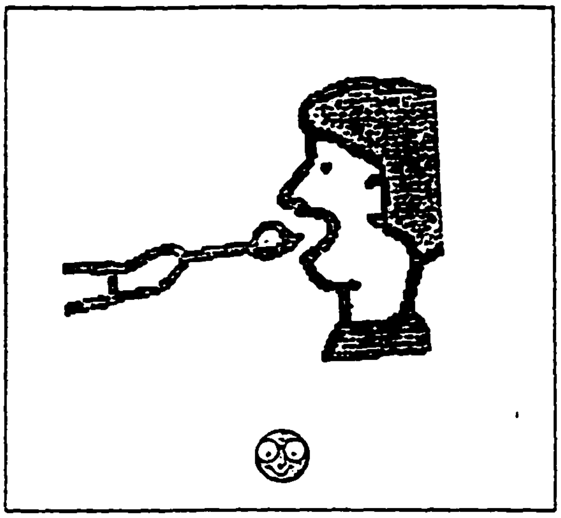
Appendix C

Stimulus Pictures

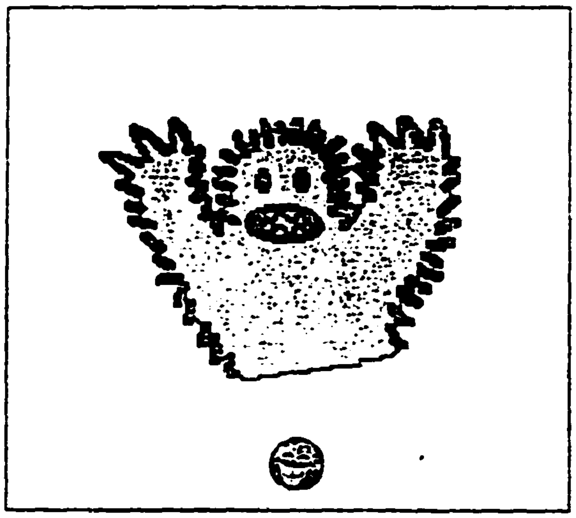
FEET



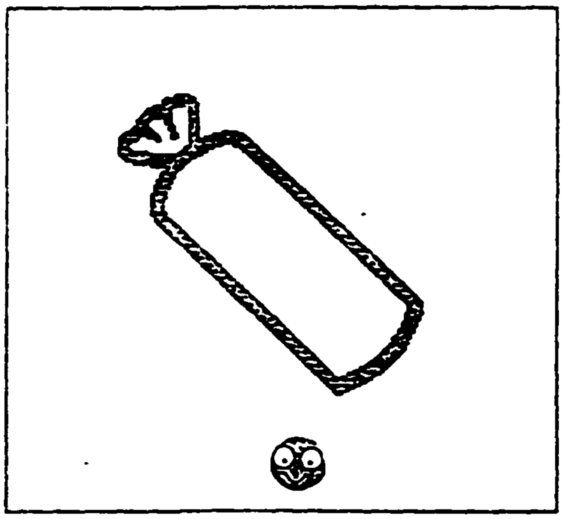
FEED



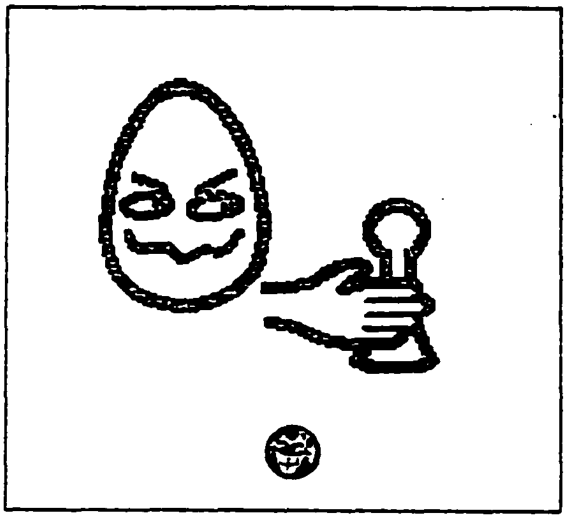
ZEET



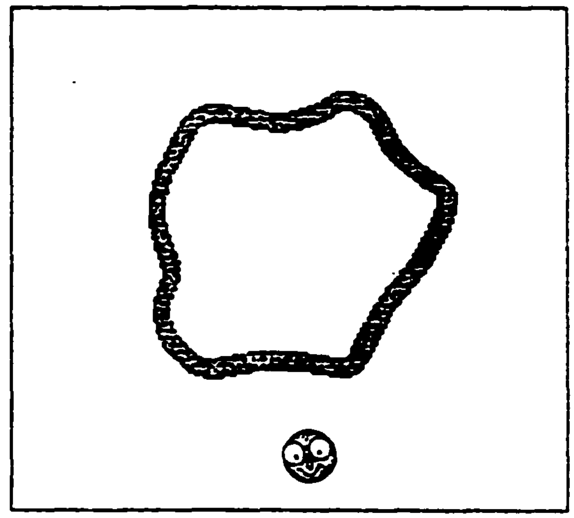
ZEED



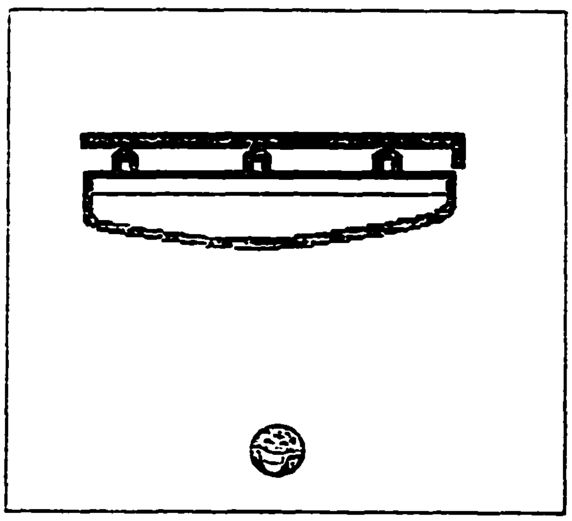
CHEAT



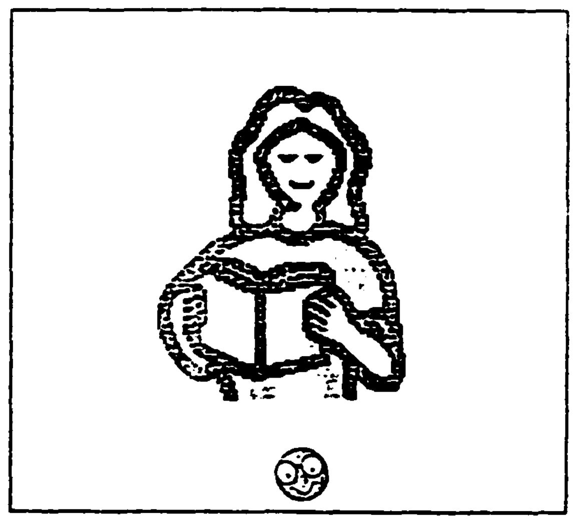
CHEAD



REAT



READ



Appendix D

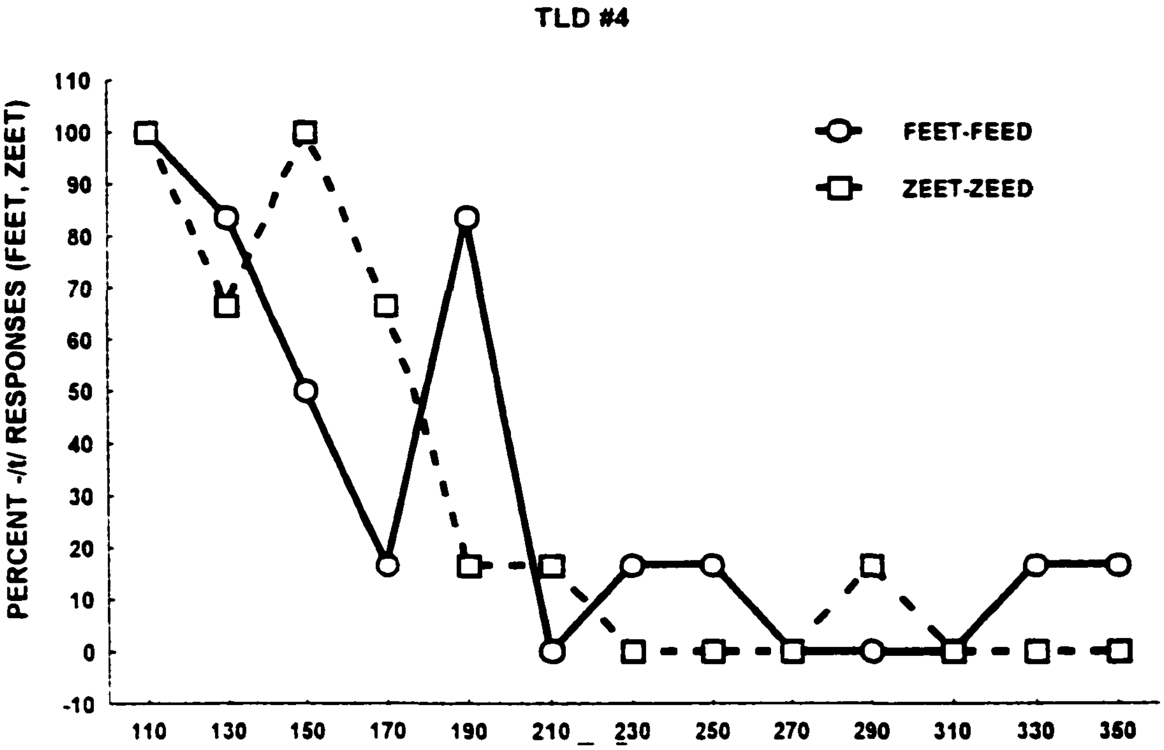
Mean (Standard Deviation) number of training trials needed to reach criterion for each stimulus condition: Comparison of TLD and SLI.

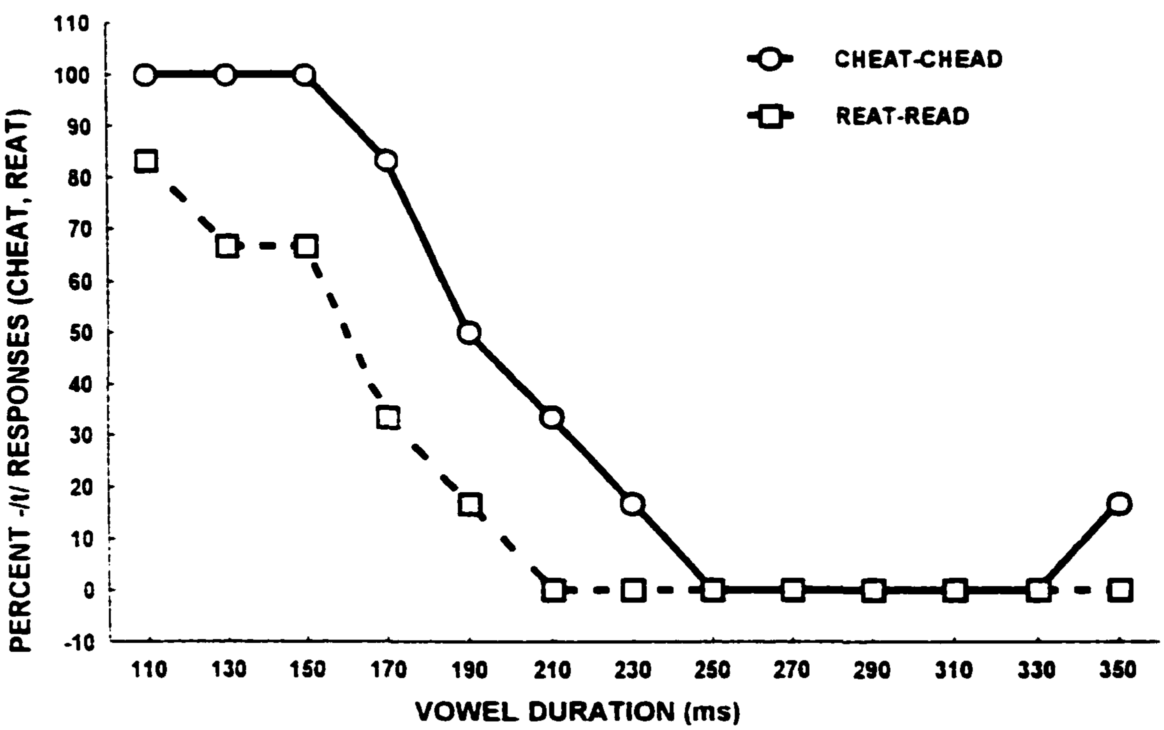
	TLD (N=13)	SLI (N=12)	t (23)	p
FEET-FEED	4 46 (88)	4 92 (1 38)	- 99304	33
ZEET-ZEED*	4 08 (28)	4.58 (.79)	-2 16674	04*
CHEAT-CHEAD	4 62 (96)	4 83 (1 27)	- 48701	63
REAT-READ	4 69 (1 11)	5 00 (95)	- 74066	47

* The SLI group required one-half of one more training trials for the ZEET-ZEED continuum than the TLD group

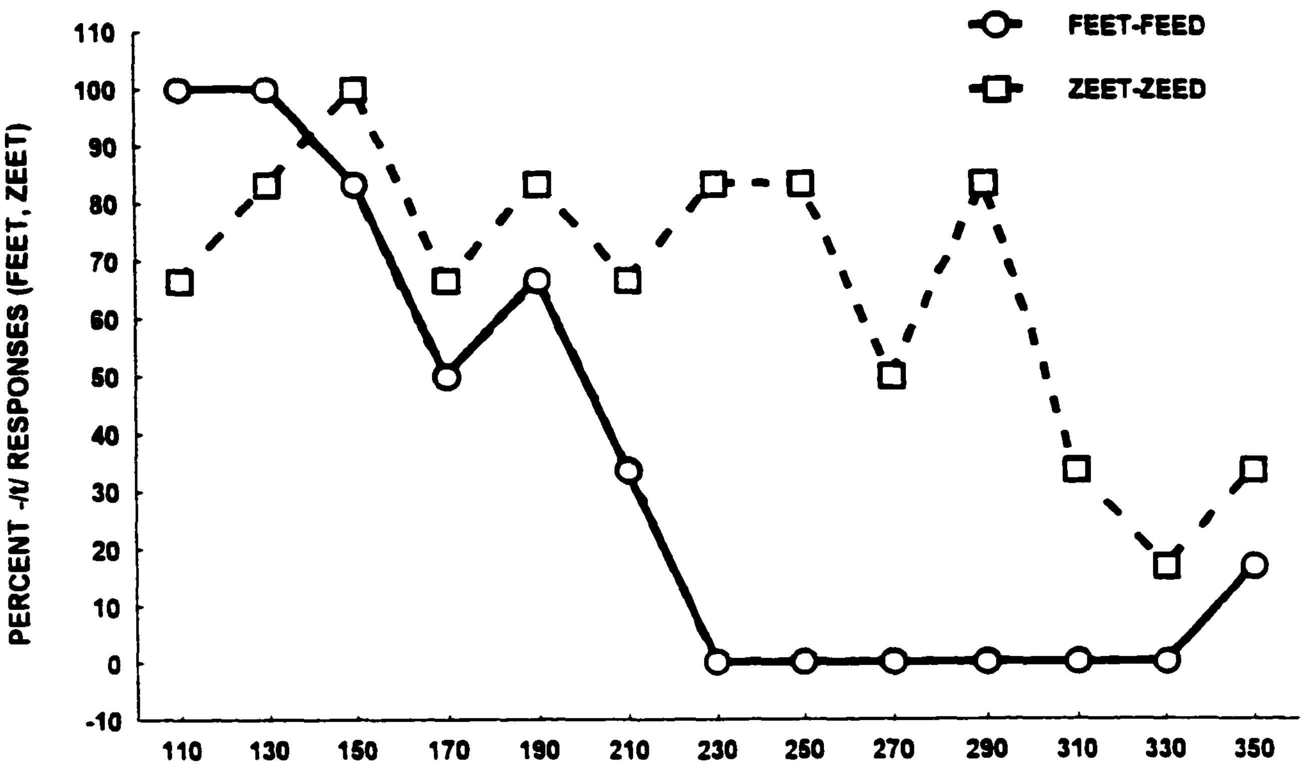
Appendix E

Individual child mean response graphs by group (TLD or SLI)

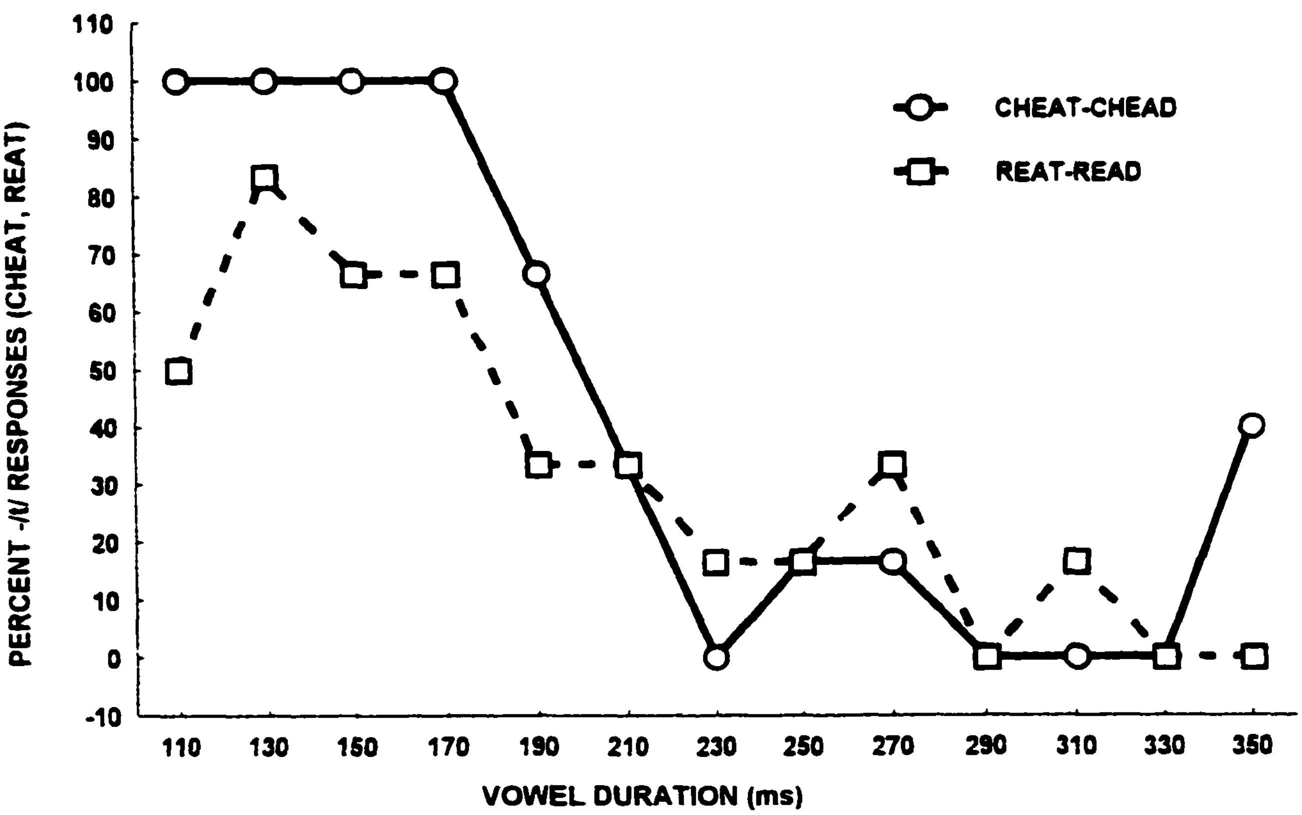




TLD #5

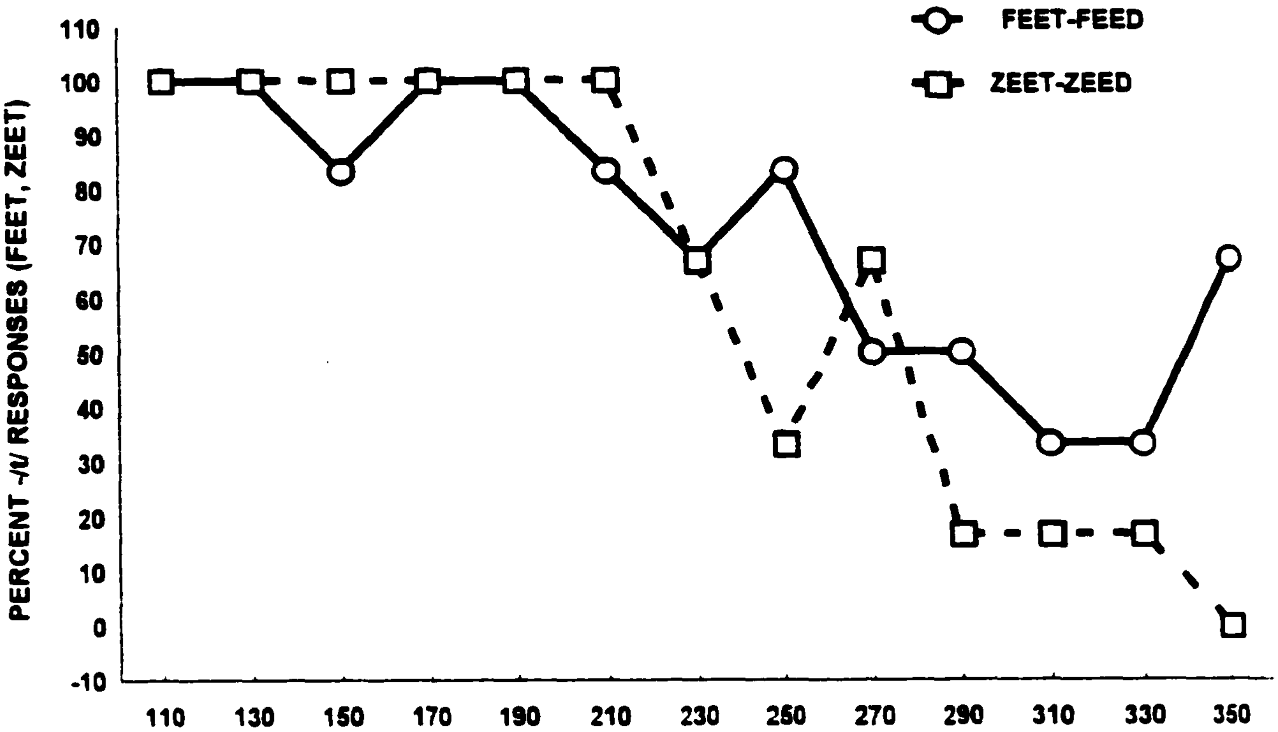


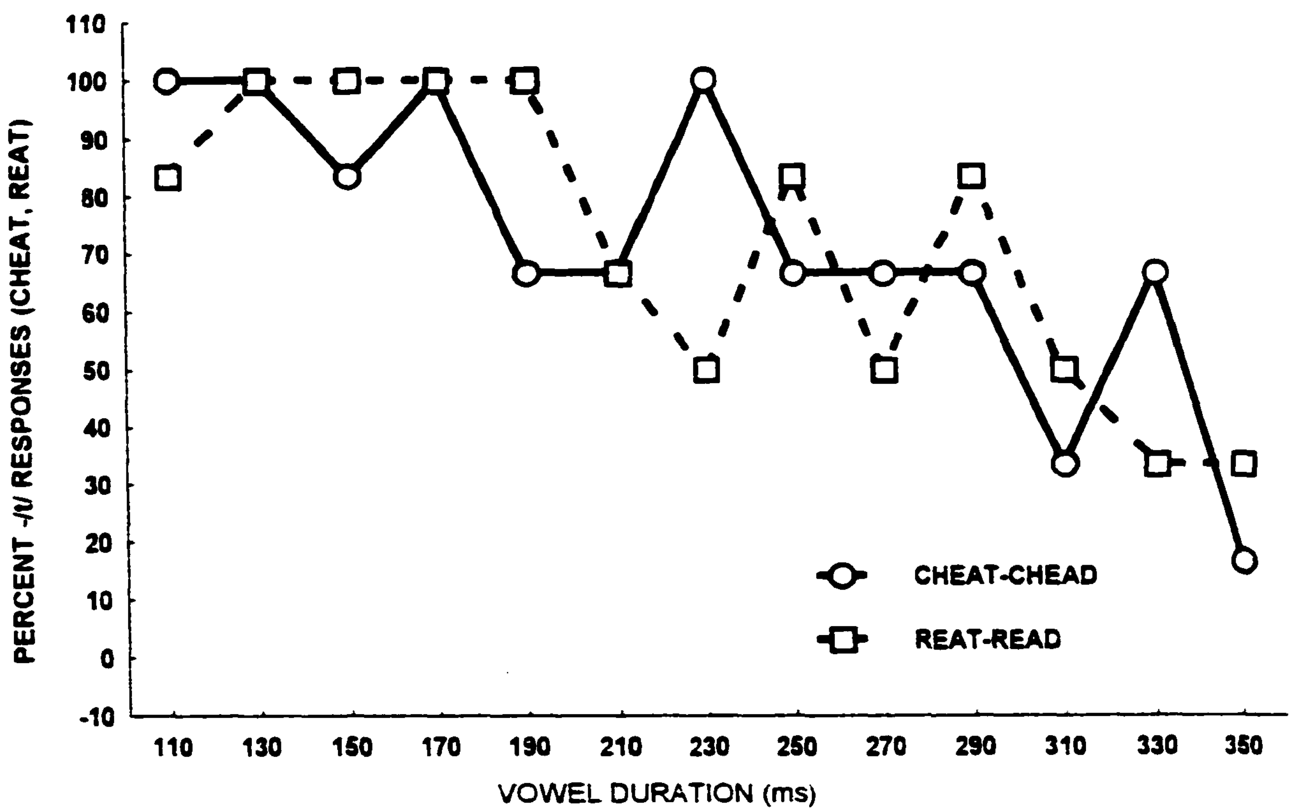
FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350



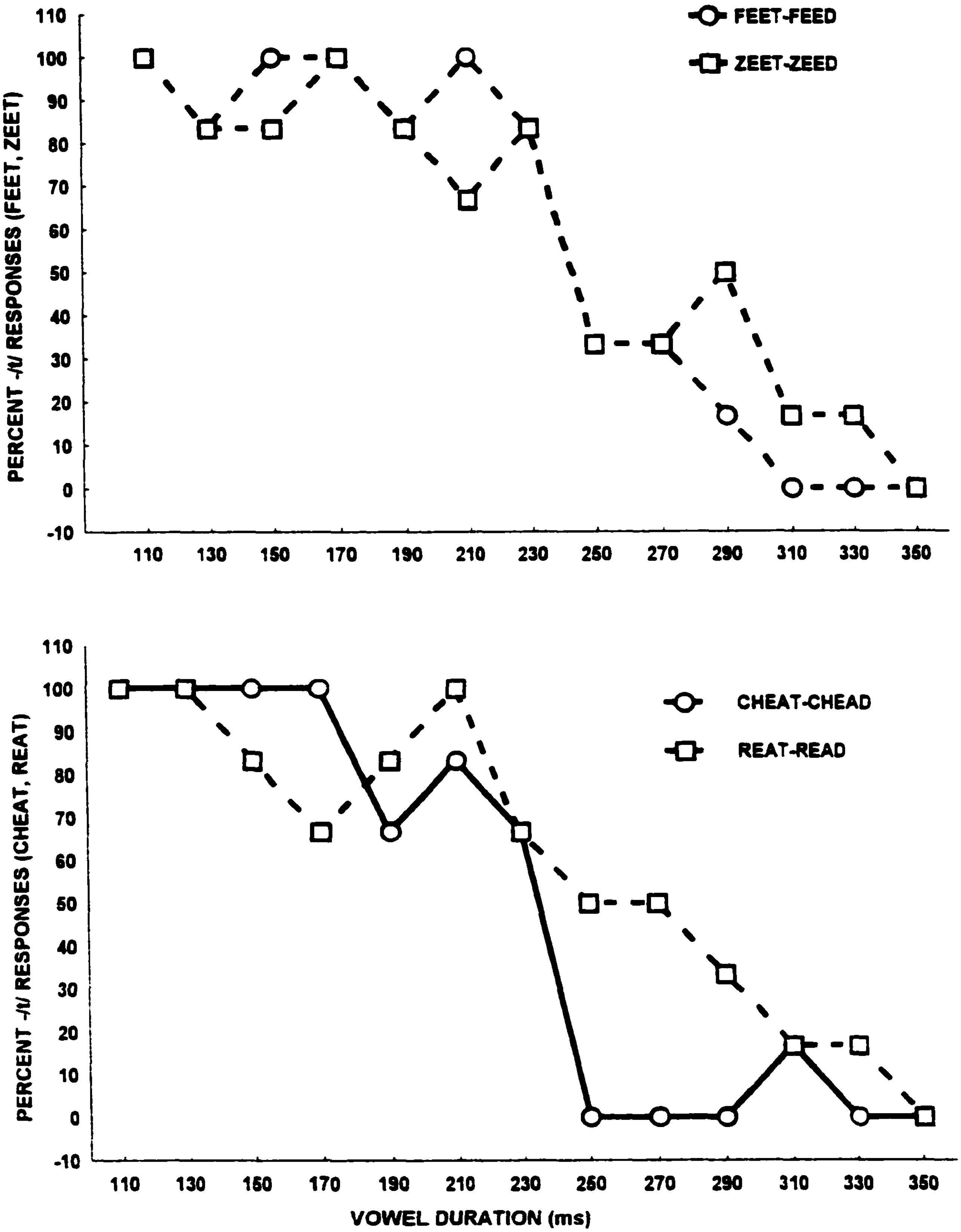
CHEAT-CHEAD
REAT-READ
PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

TLD #8

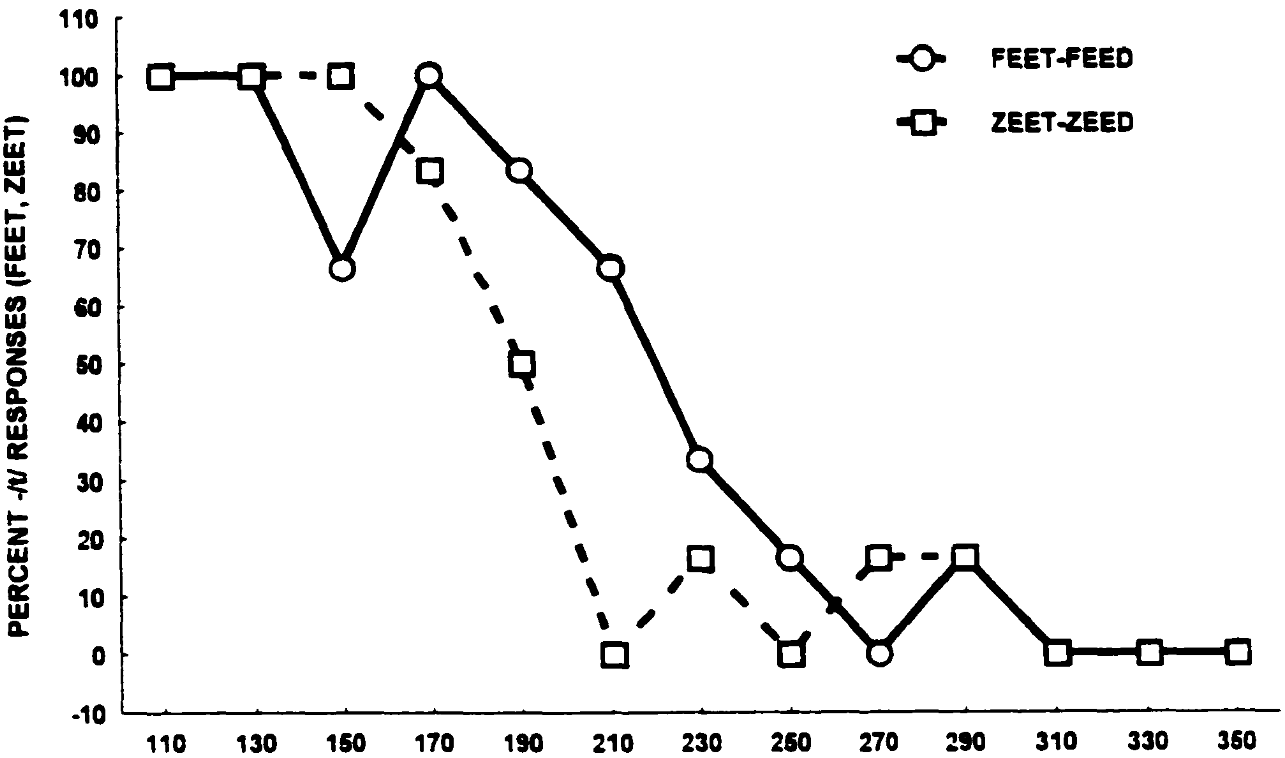

FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350

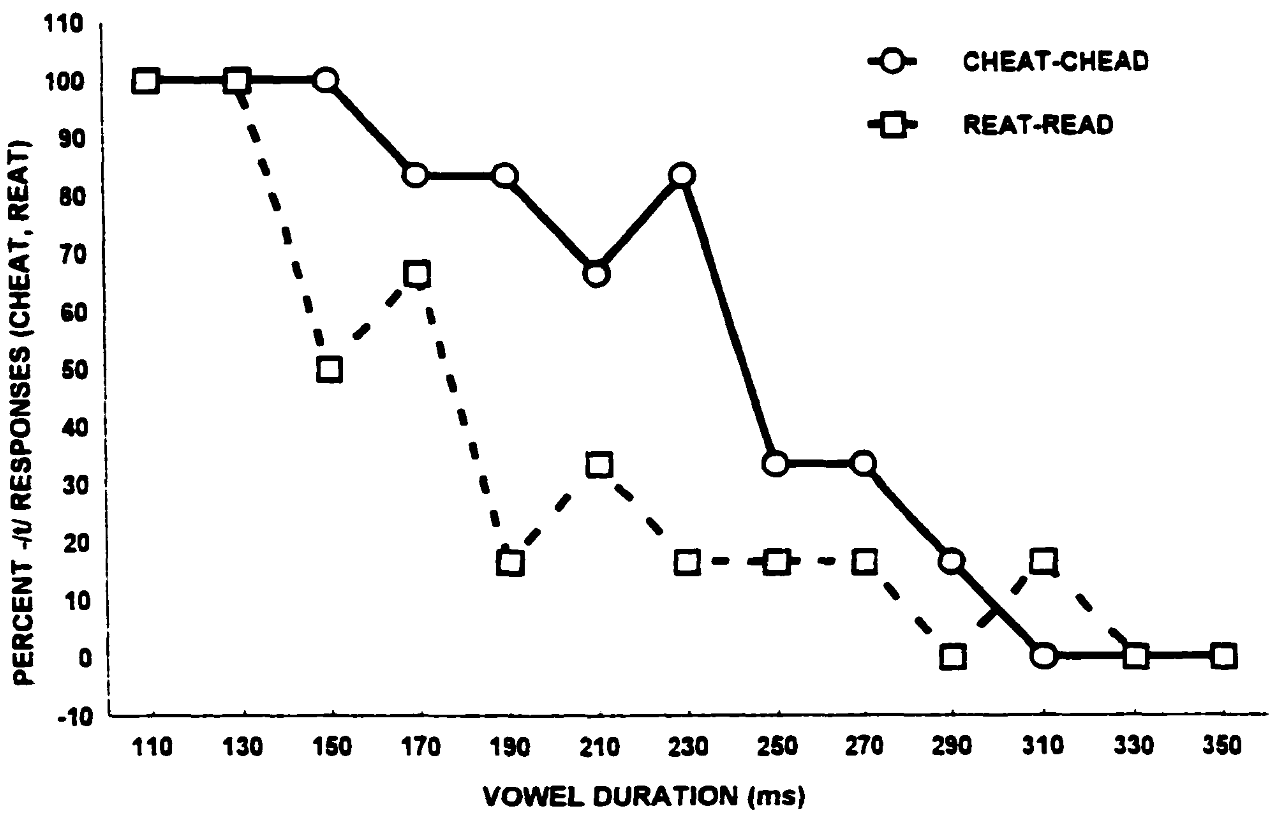

PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

TLD #12


FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110 130 150 170 190 210 230 250 270 290 310 330 350
CHEAT-CHEAD
REAT-READ
PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110 130 150 170 190 210 230 250 270 290 310 330 350
VOWEL DURATION (ms)

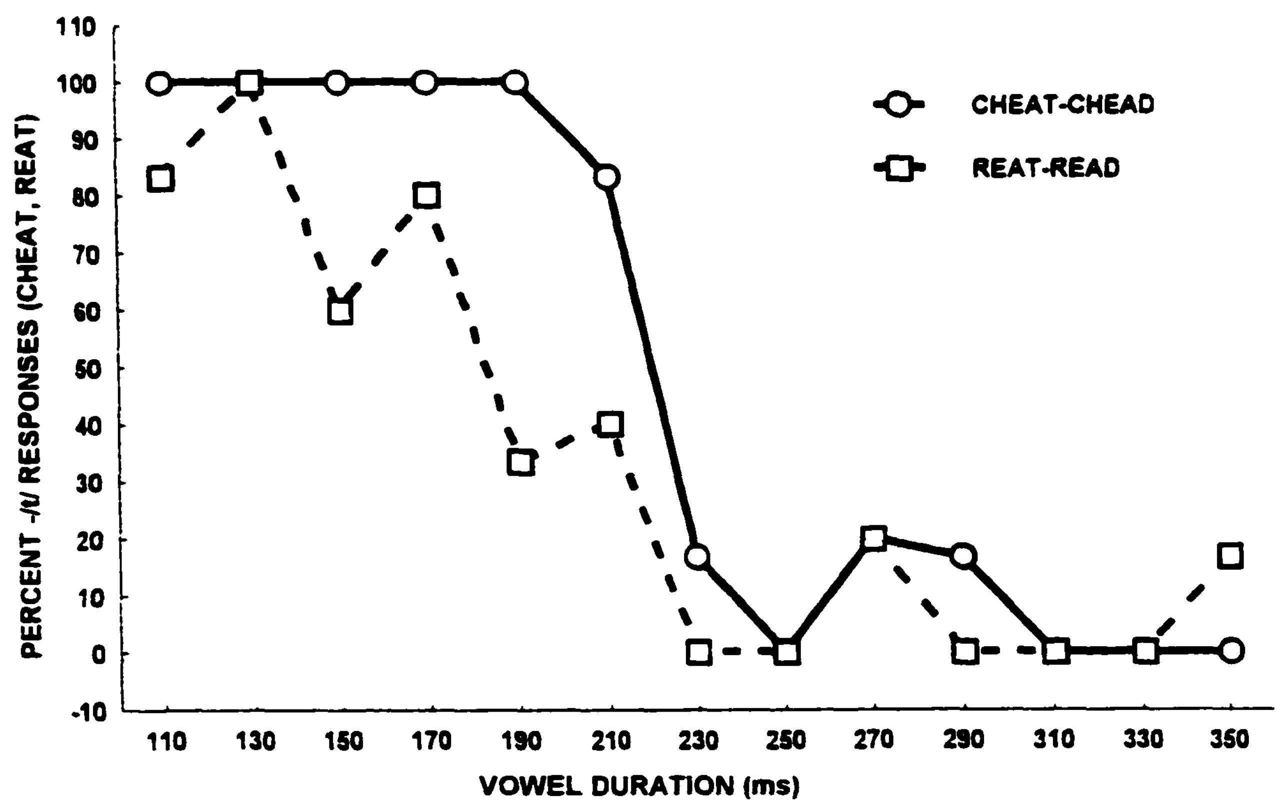
TLD#13


PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
FEET-FEED
ZEET-ZEED

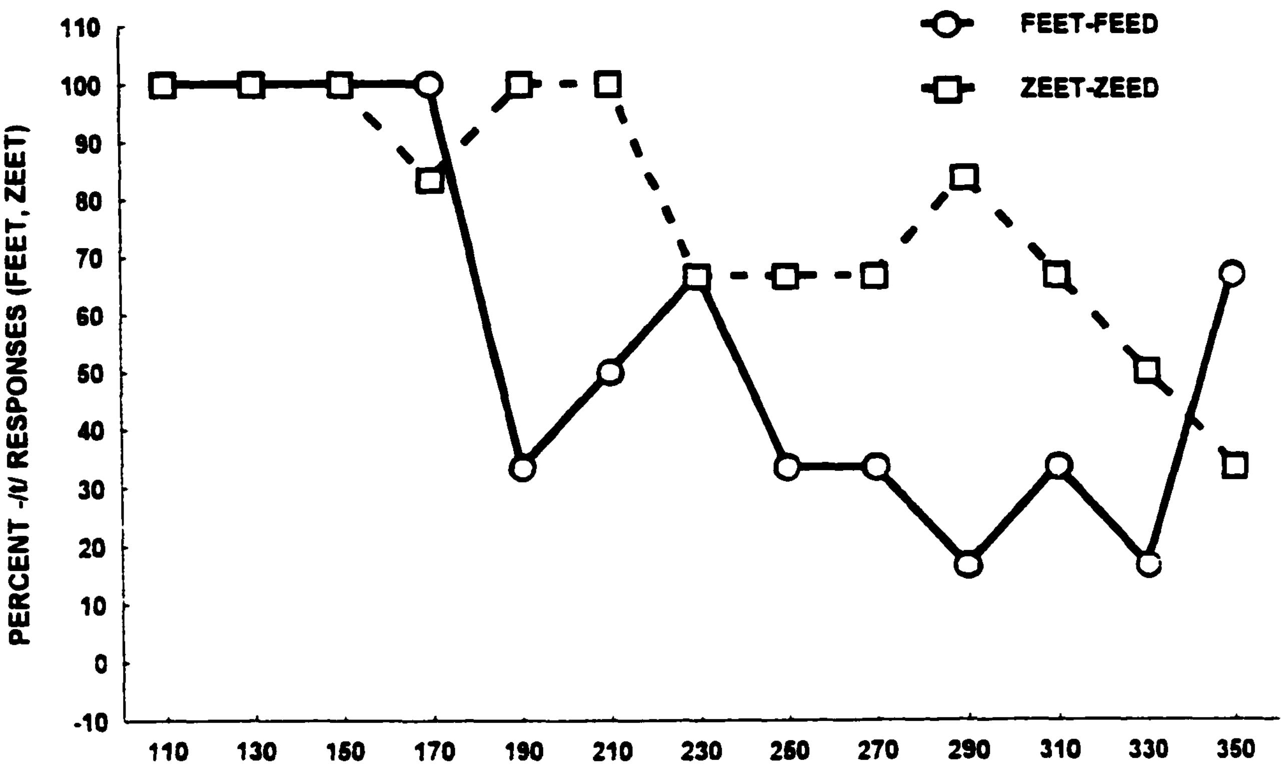

PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)
CHEAT-CHEAD
REAT-READ

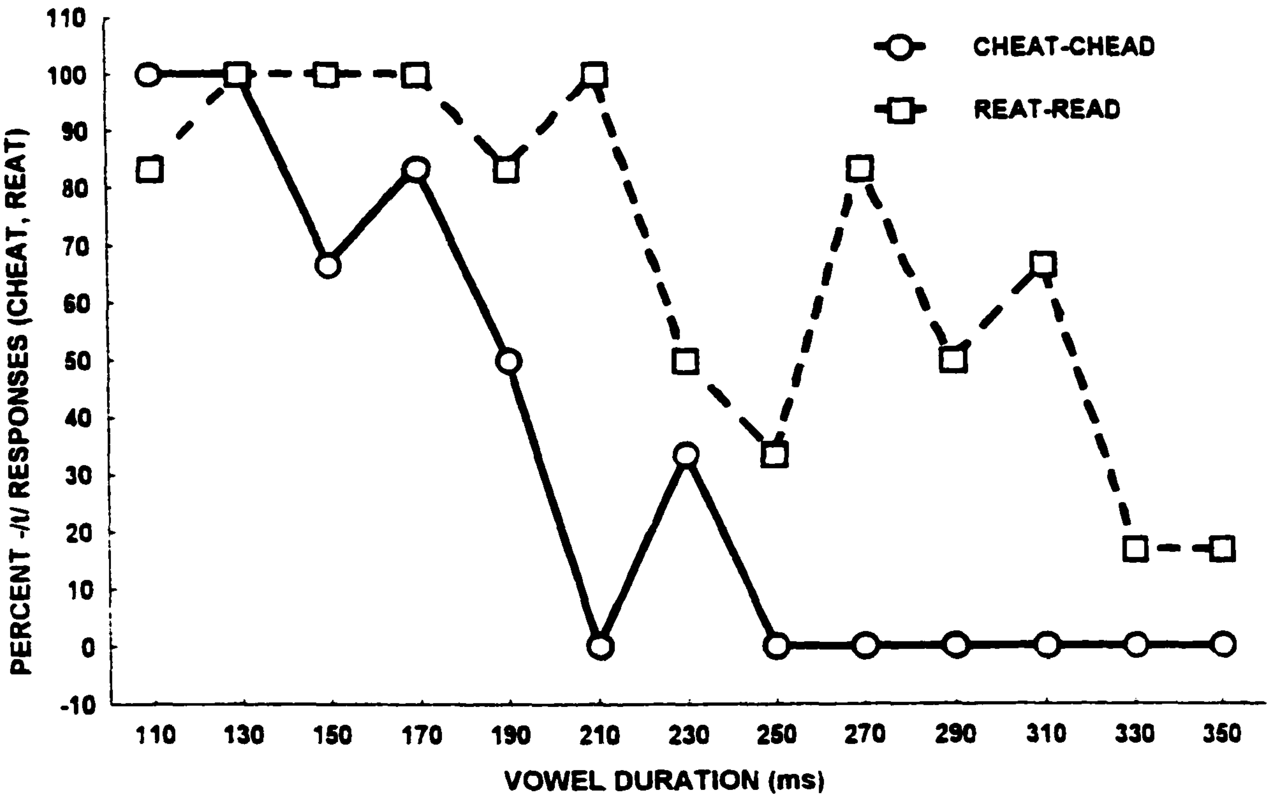
TLD#15


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350

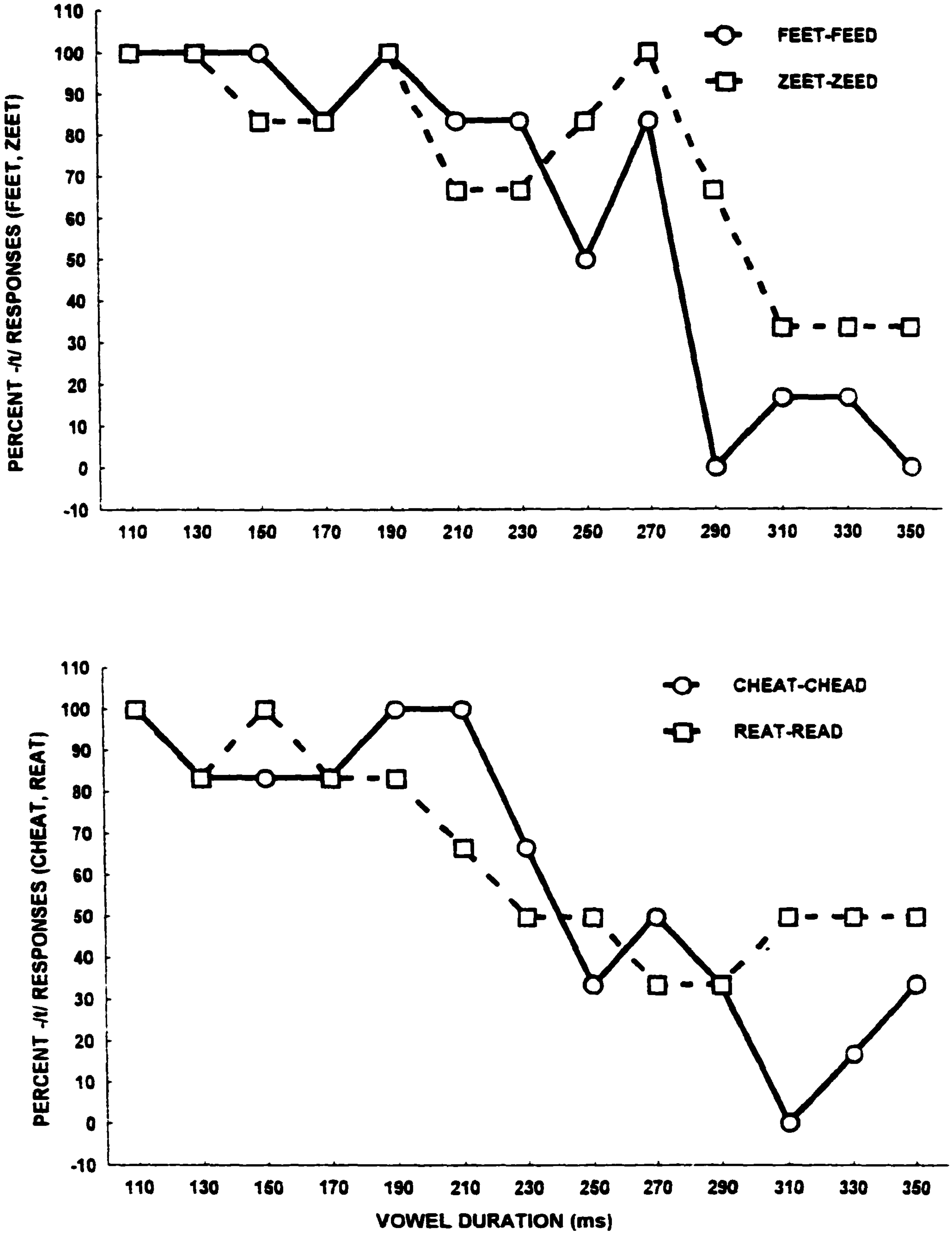

110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

TLD#18


FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350

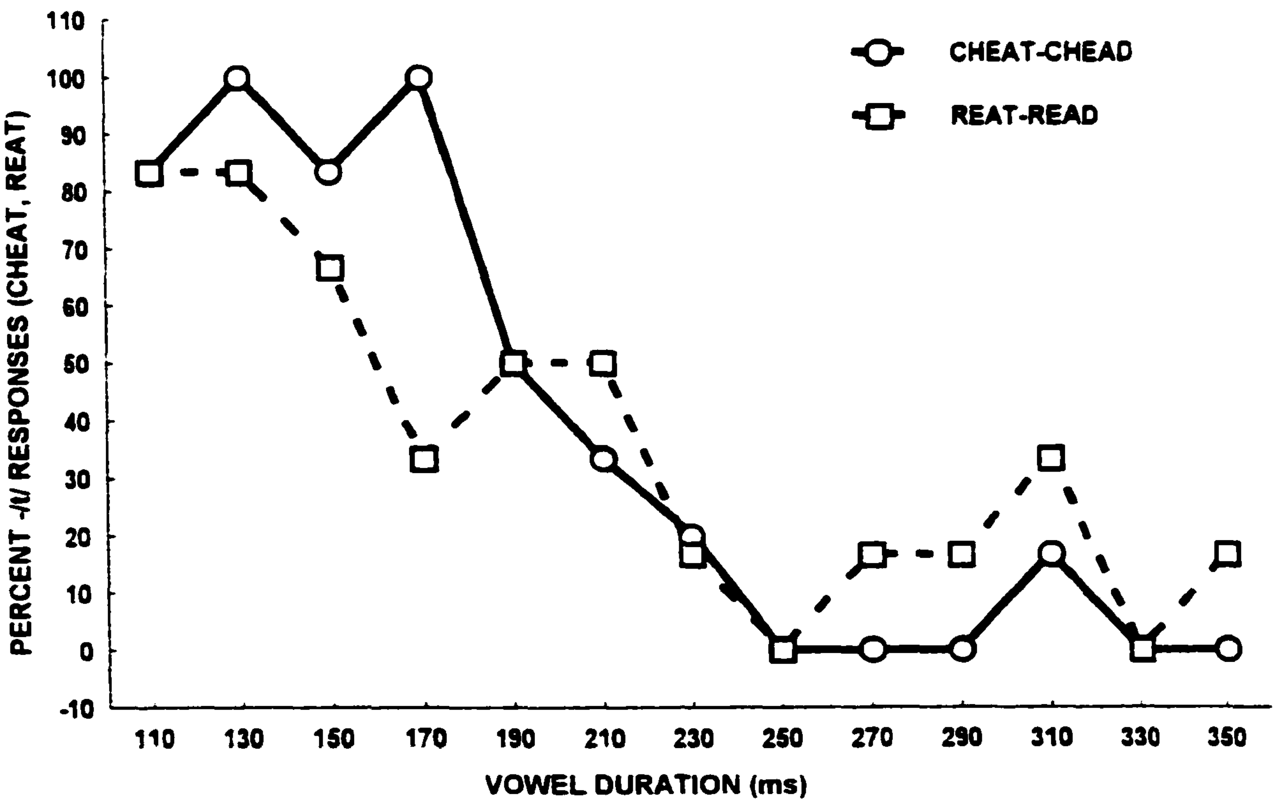

CHEAT-CHEAD
REAT-READ
PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

TLD#22

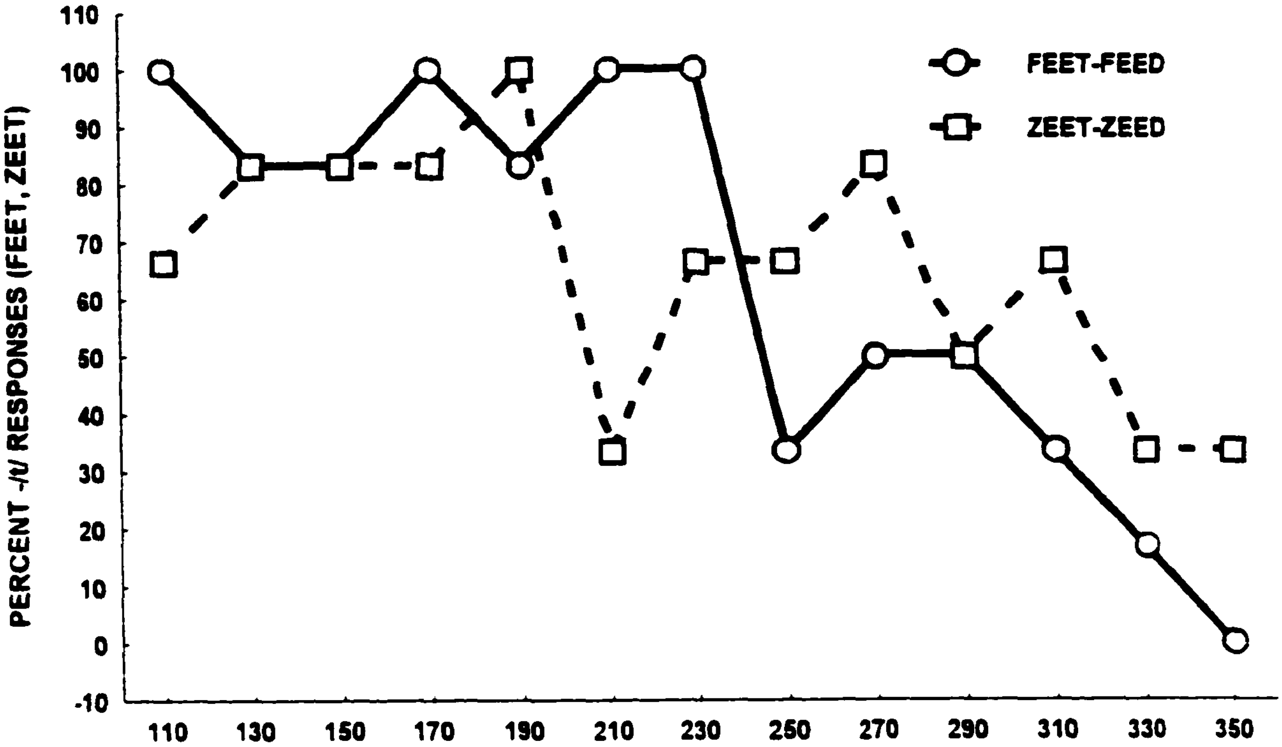

110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350
110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

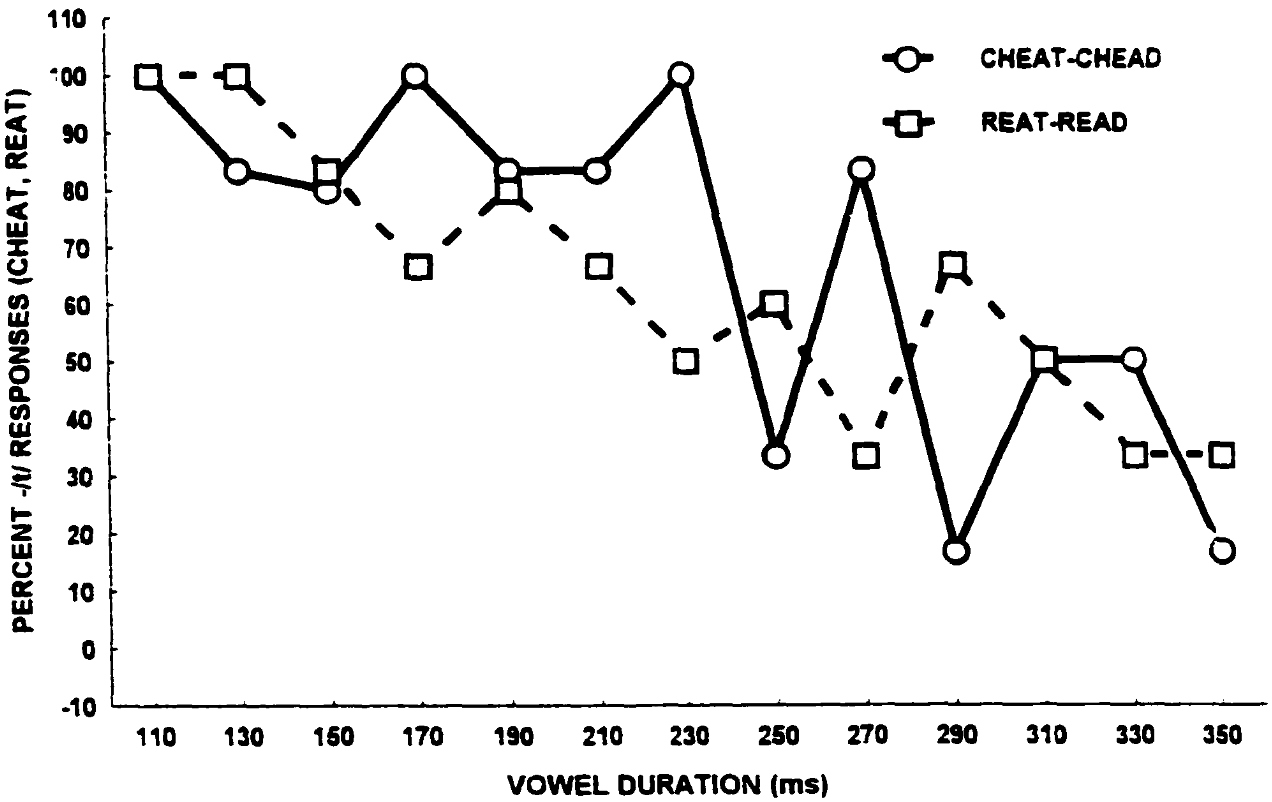
TLD#32


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

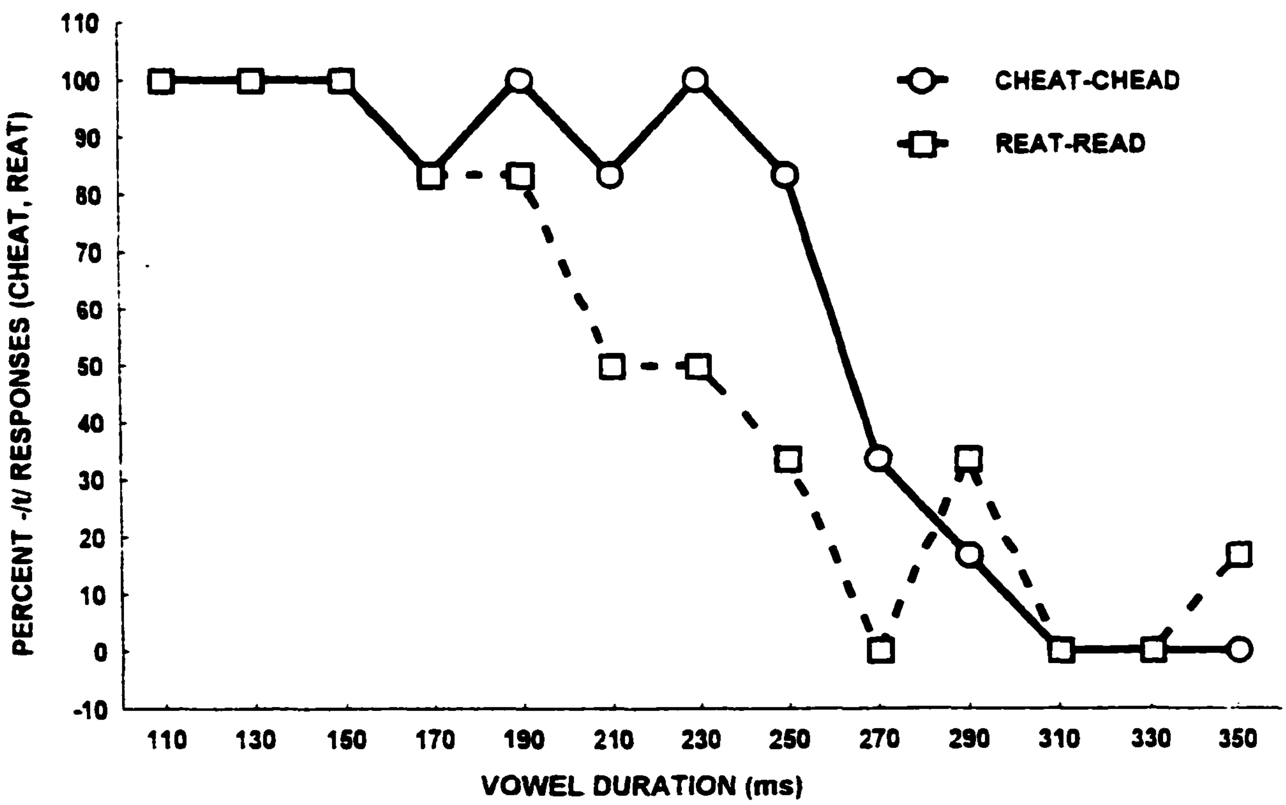
TLD#33


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350

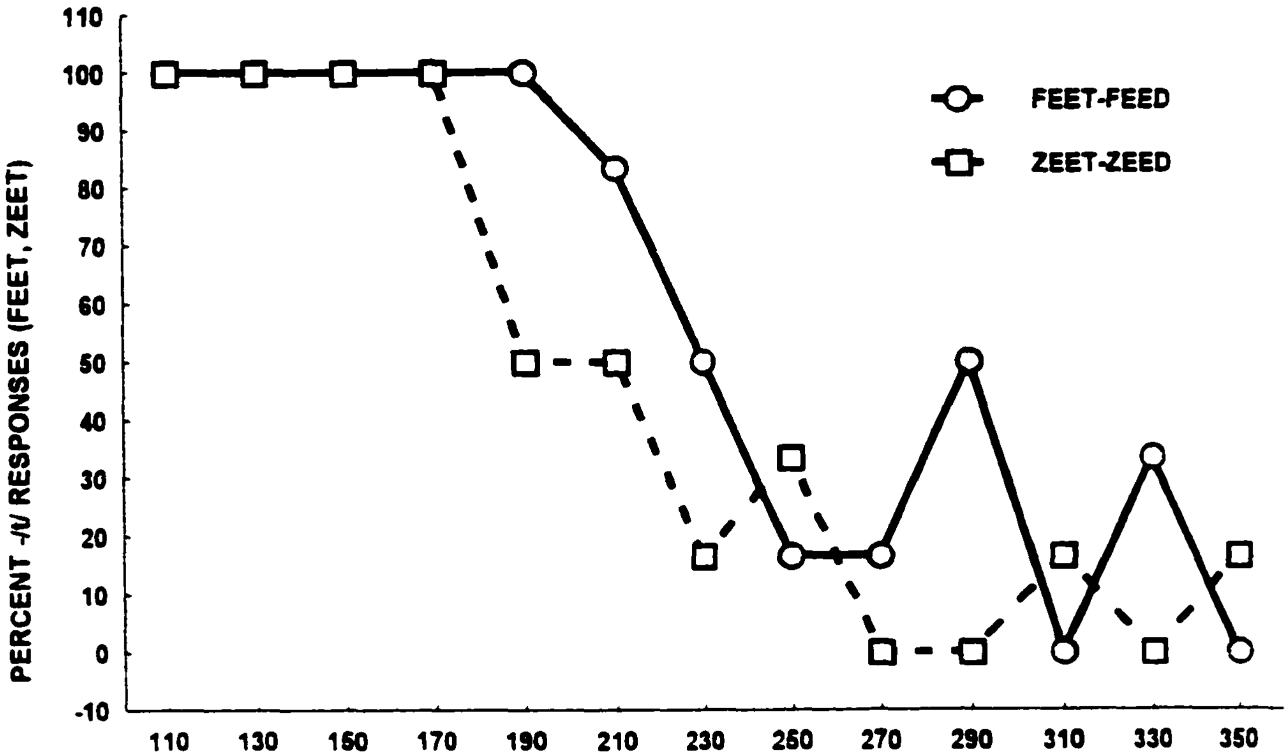

110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

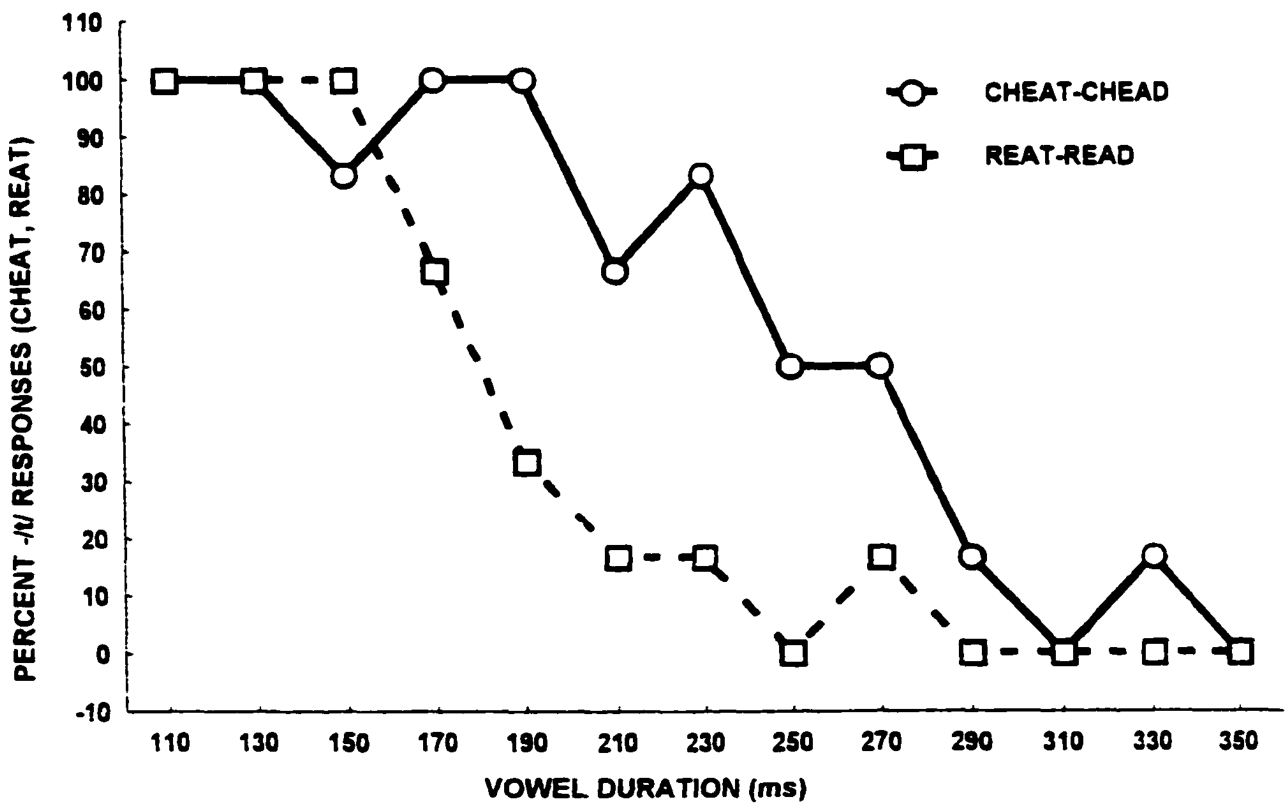
TLD#35


FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350


CHEAT-CHEAD
REAT-READ
PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

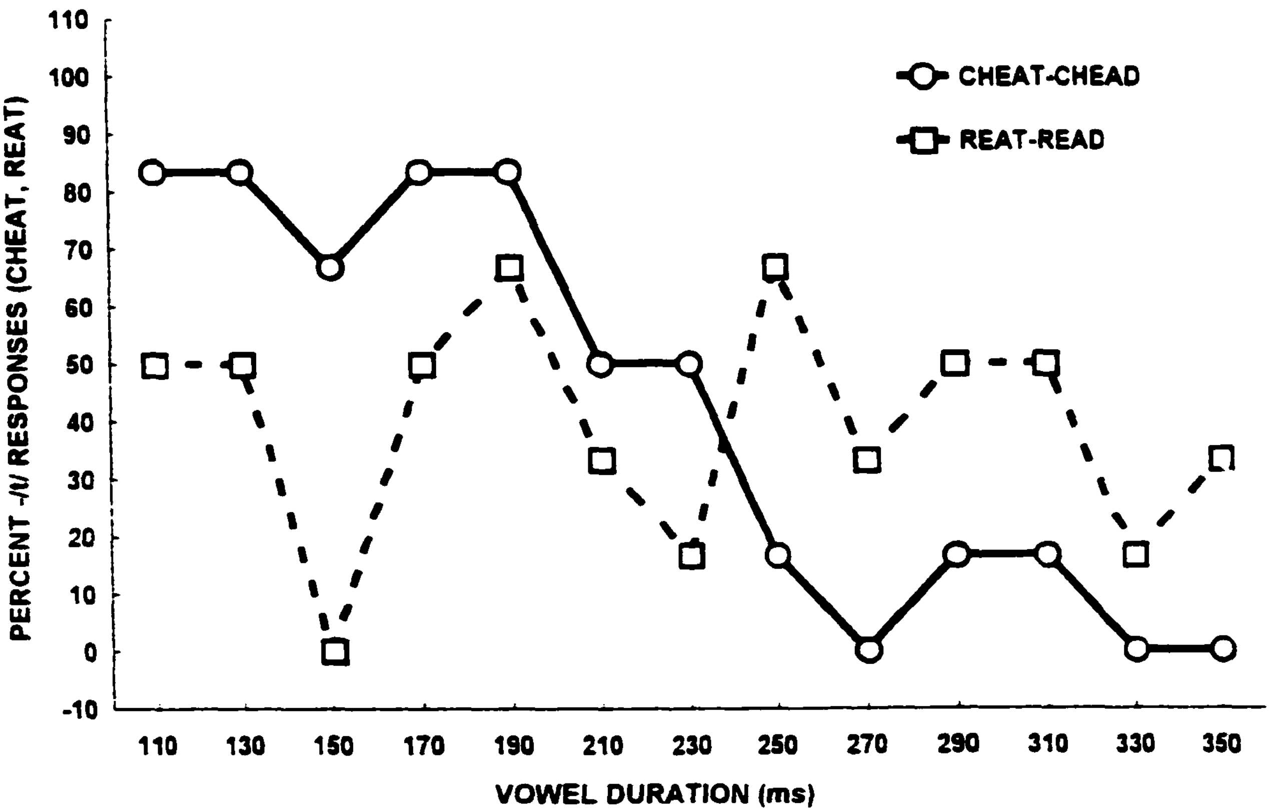
TLD#36


PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350


PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

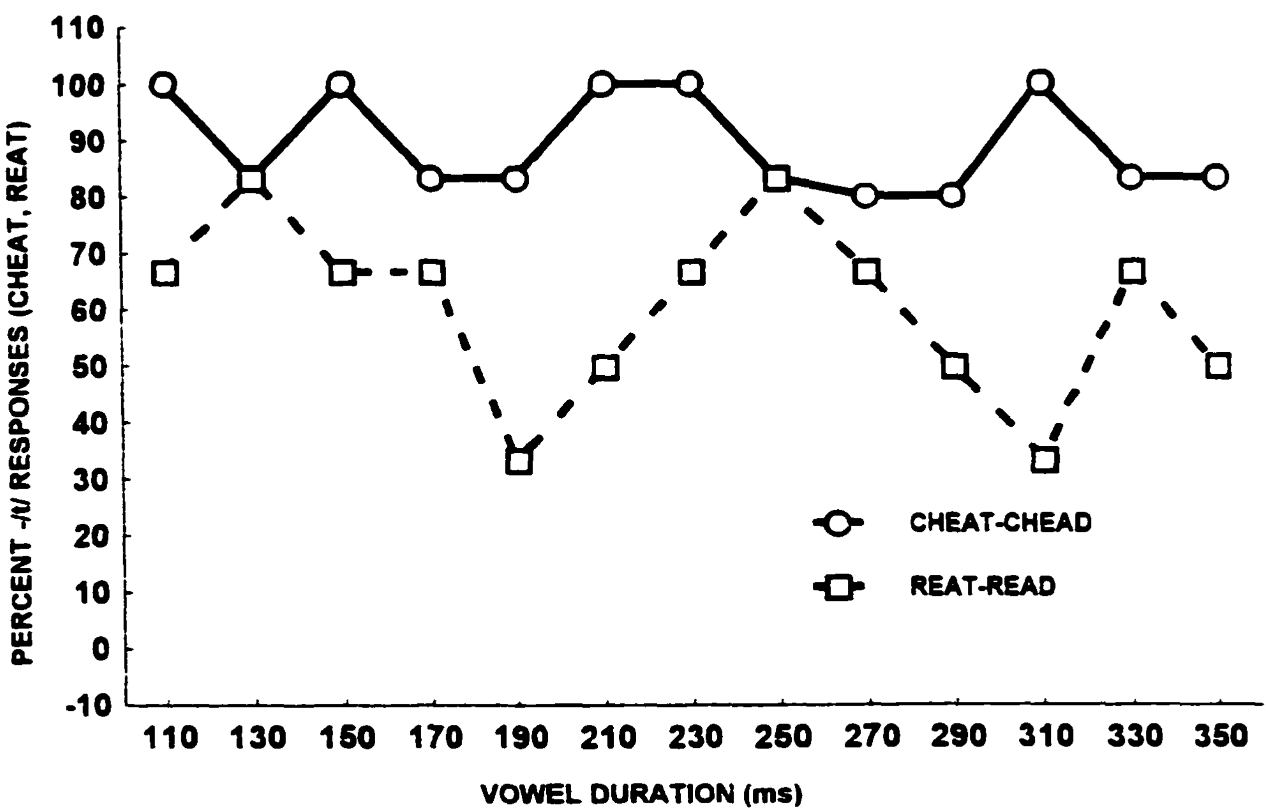
TLD#37


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350

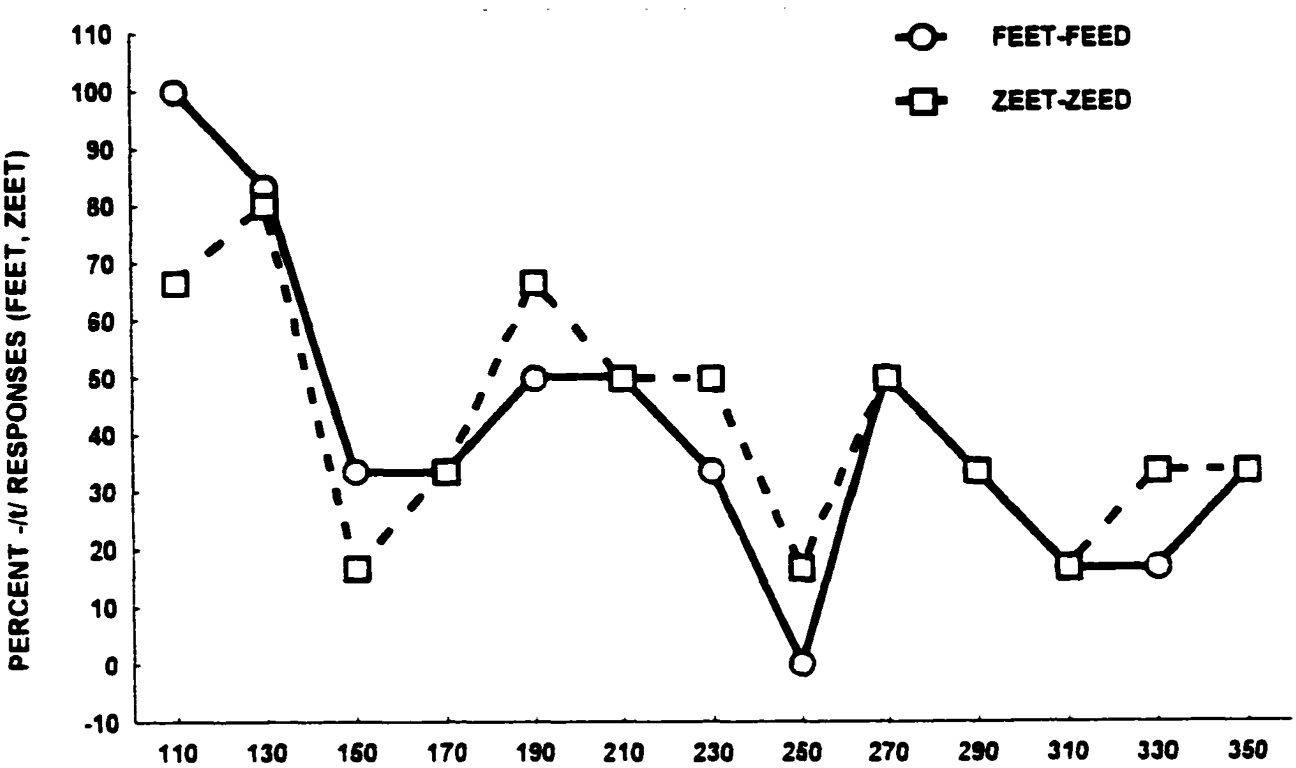

110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

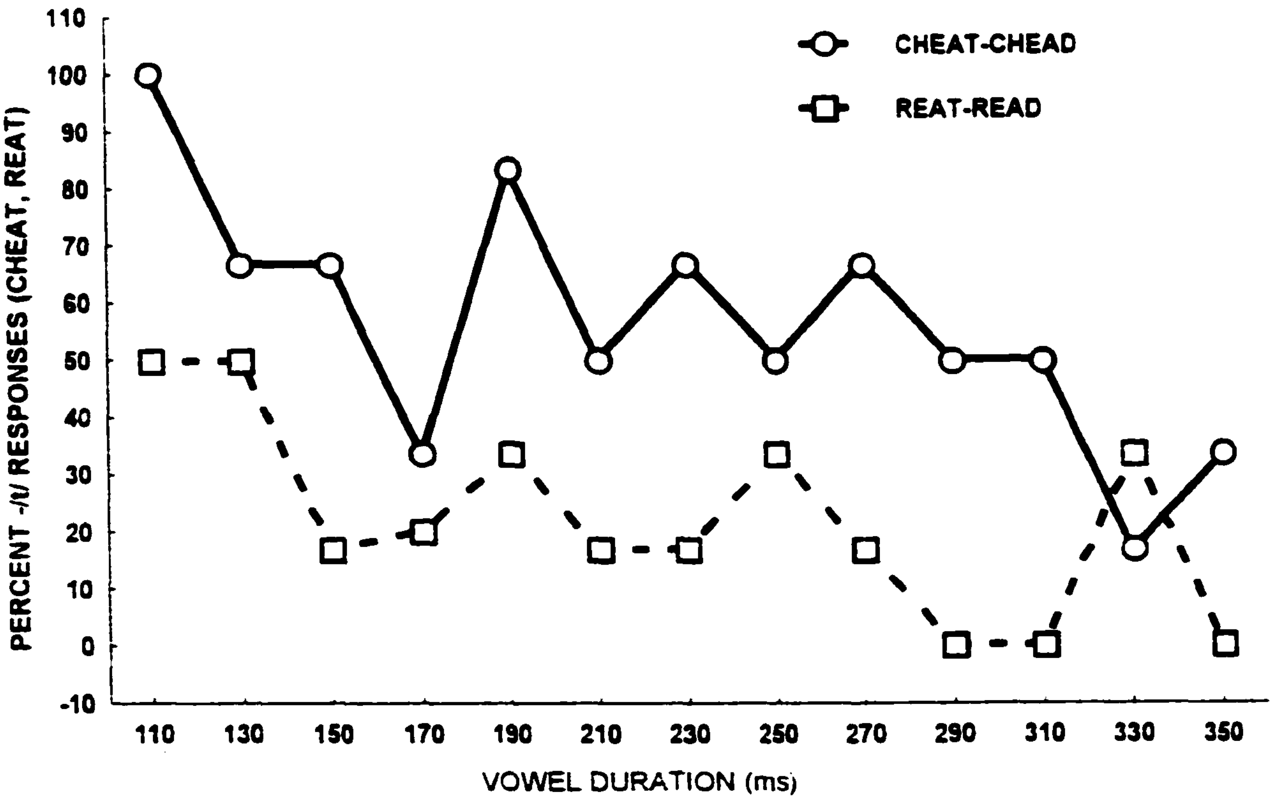
SLI #7


FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110 130 150 170 190 210 230 250 270 290 310 330 350

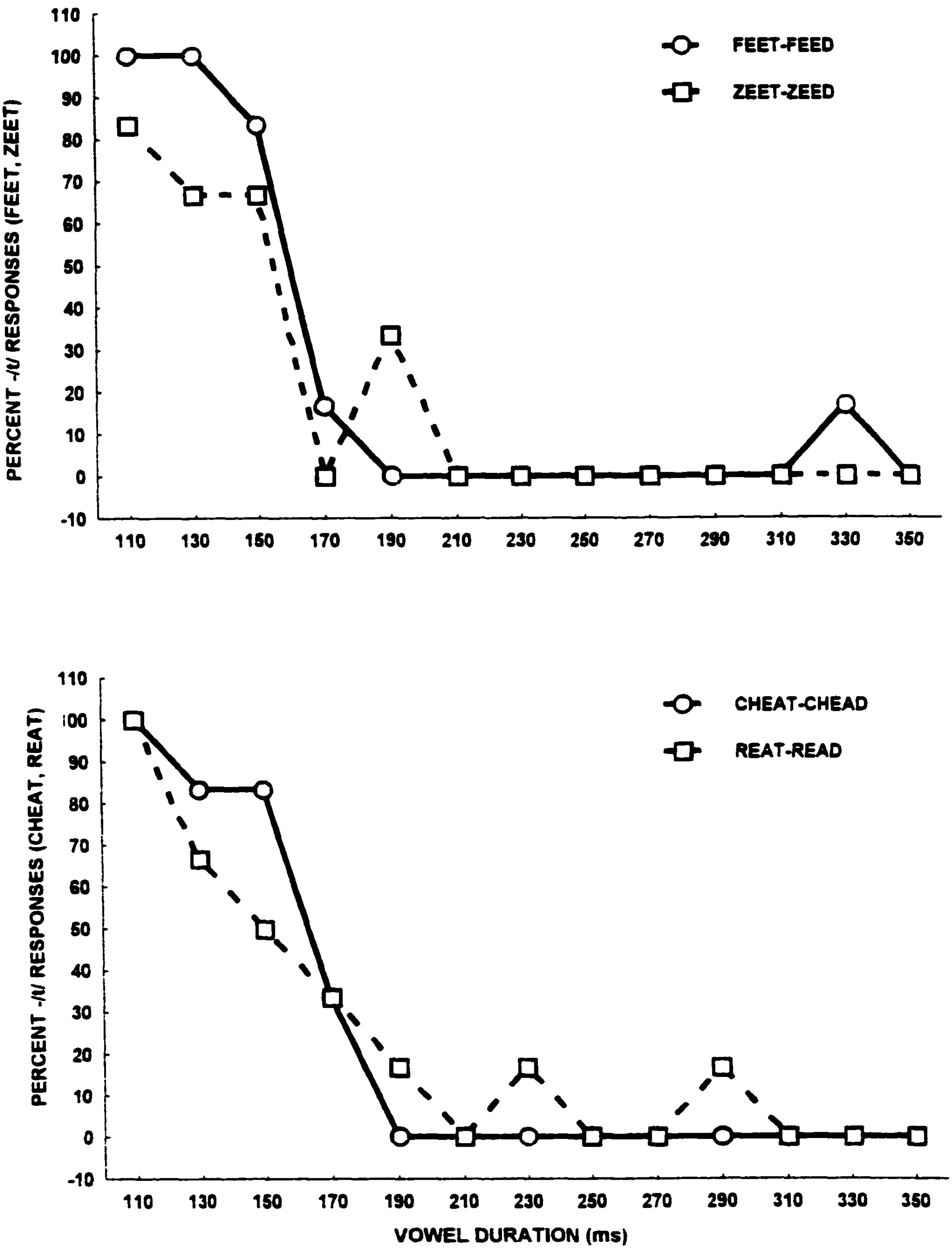

PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
CHEAT-CHEAD
REAT-READ
110 130 150 170 190 210 230 250 270 290 310 330 350
VOWEL DURATION (ms)

SLI#10

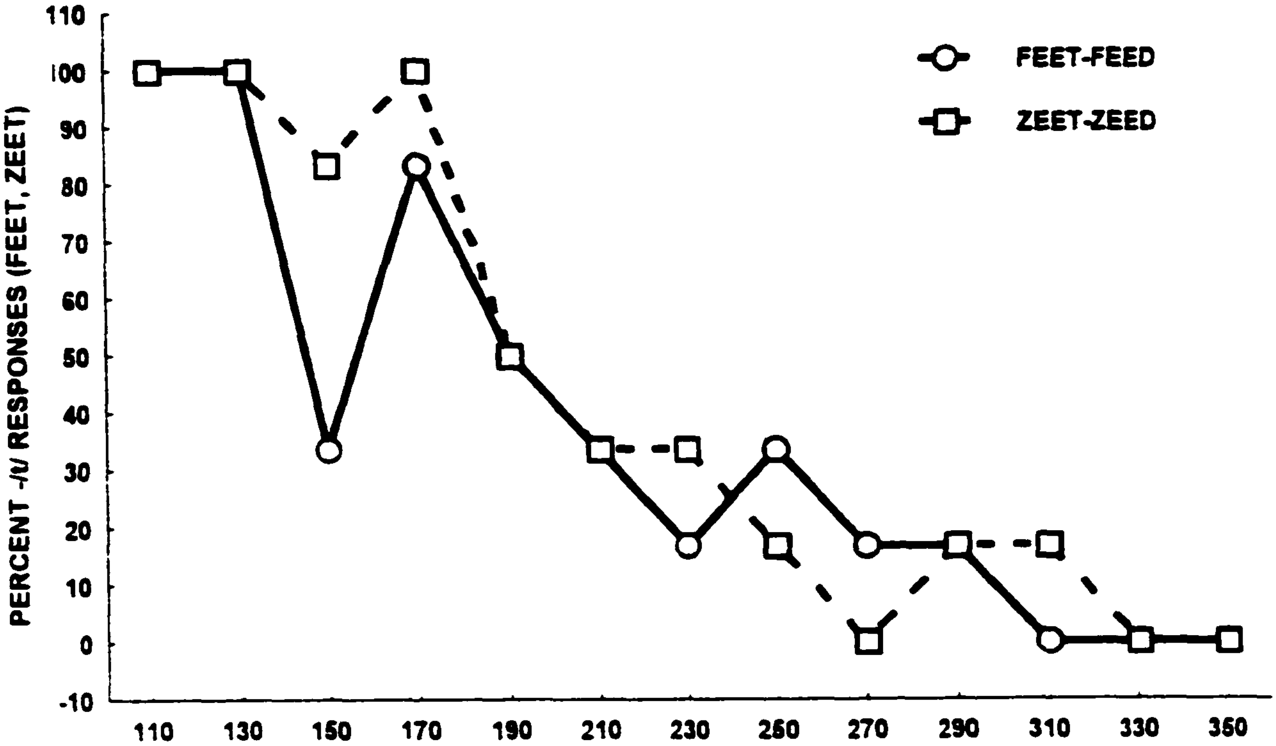

FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350

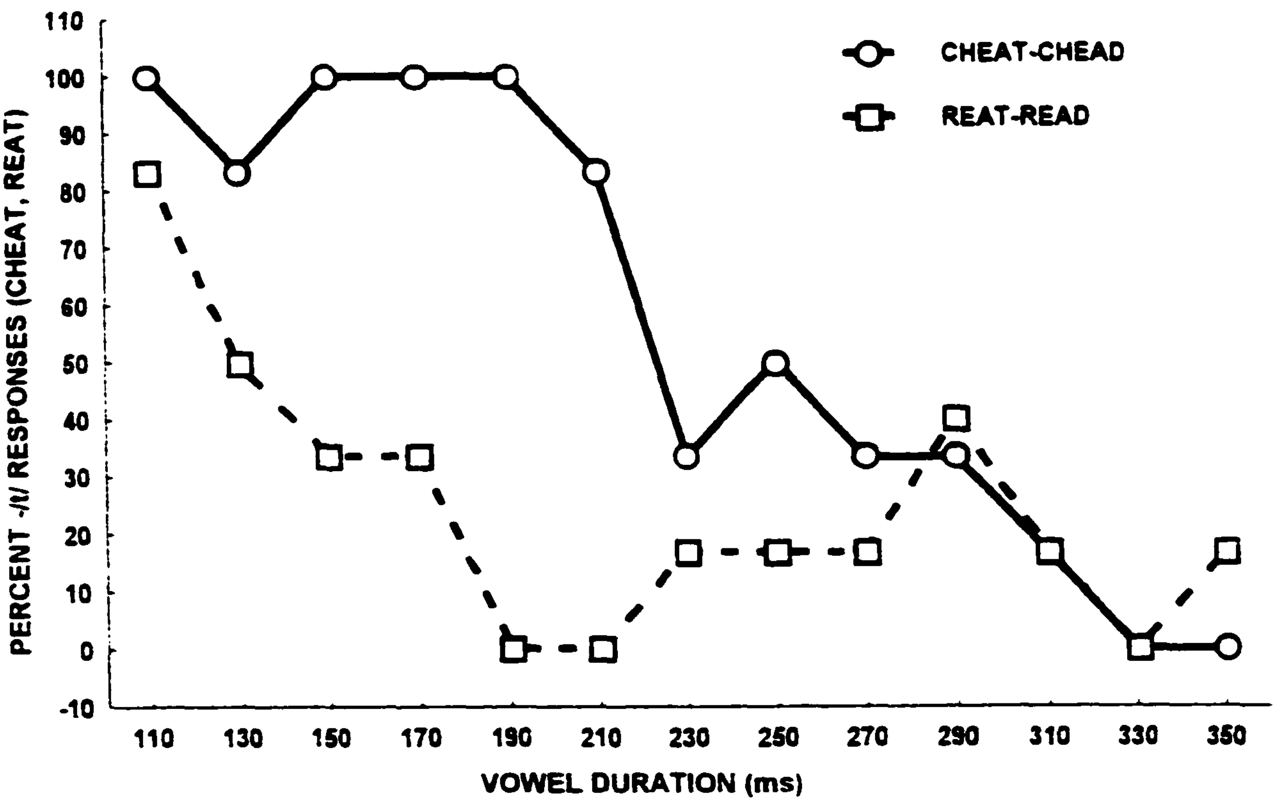

CHEAT-CHEAD
REAT-READ
PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

SLI#11

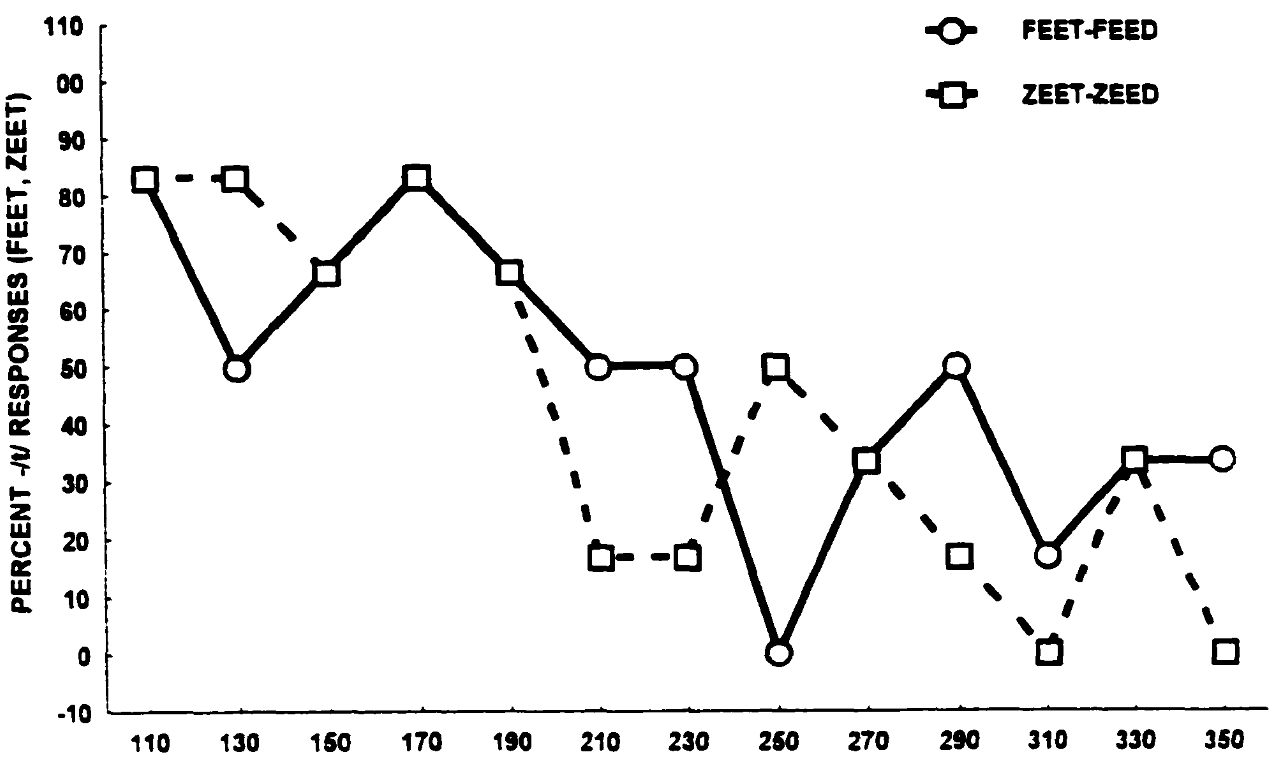

FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
CHEAT-CHEAD
REAT-READ
PERCENT -/t/ RESPONSES (CHEAT, REAT)
VOWEL DURATION (ms)

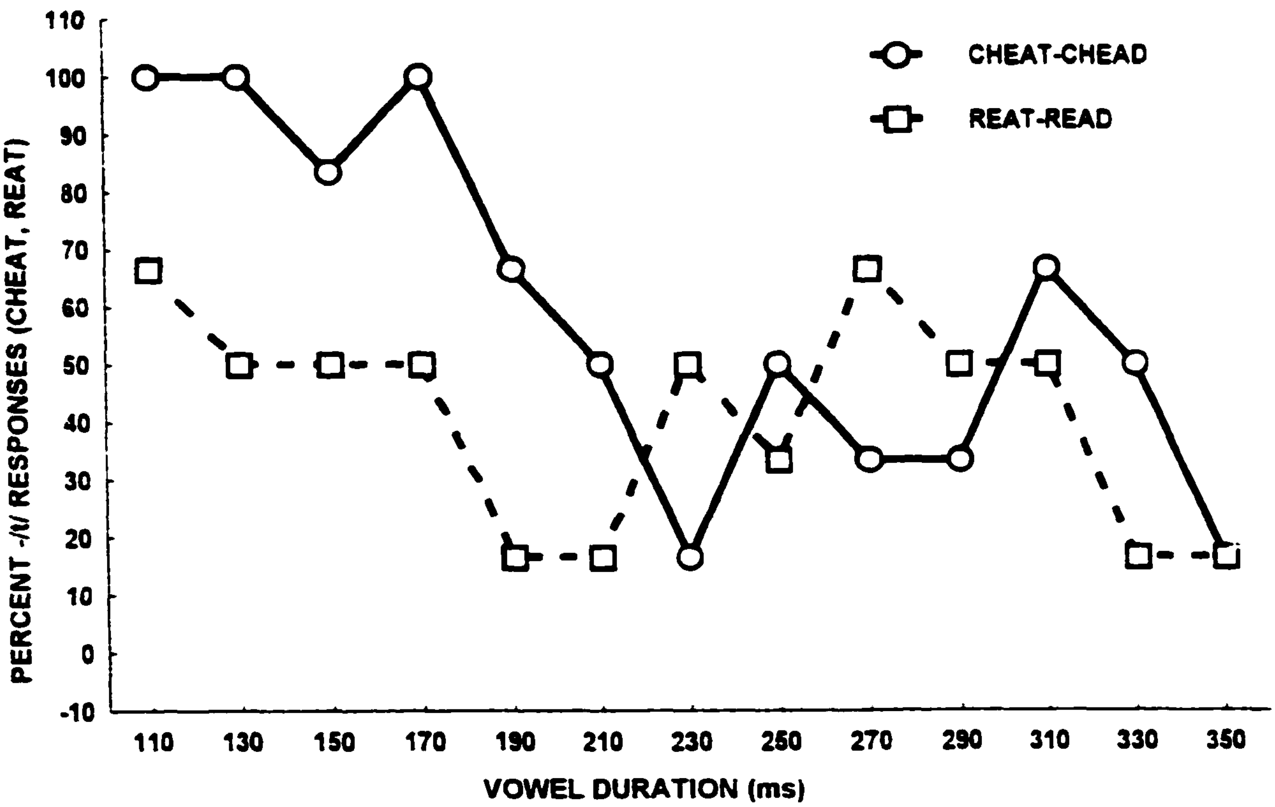
SLI#14


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350

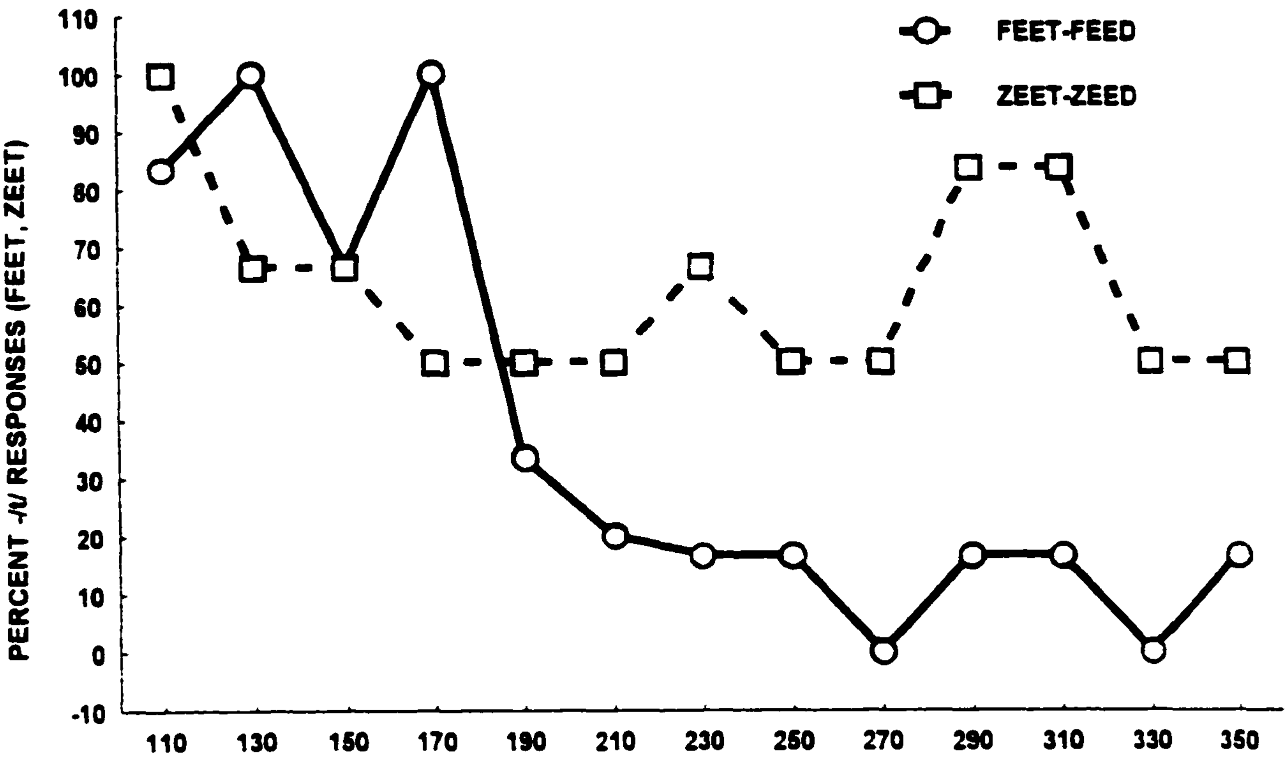

110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

SL#17

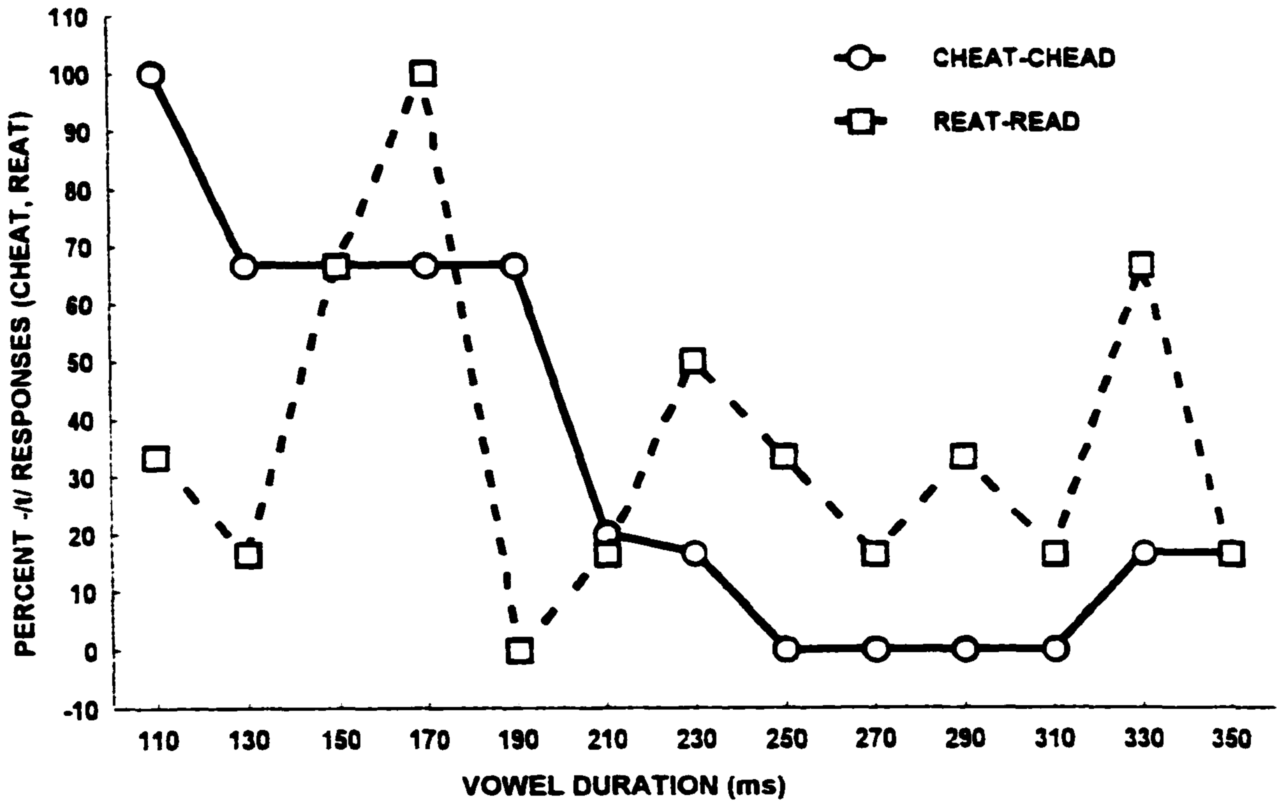

110
00
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

SLI#19



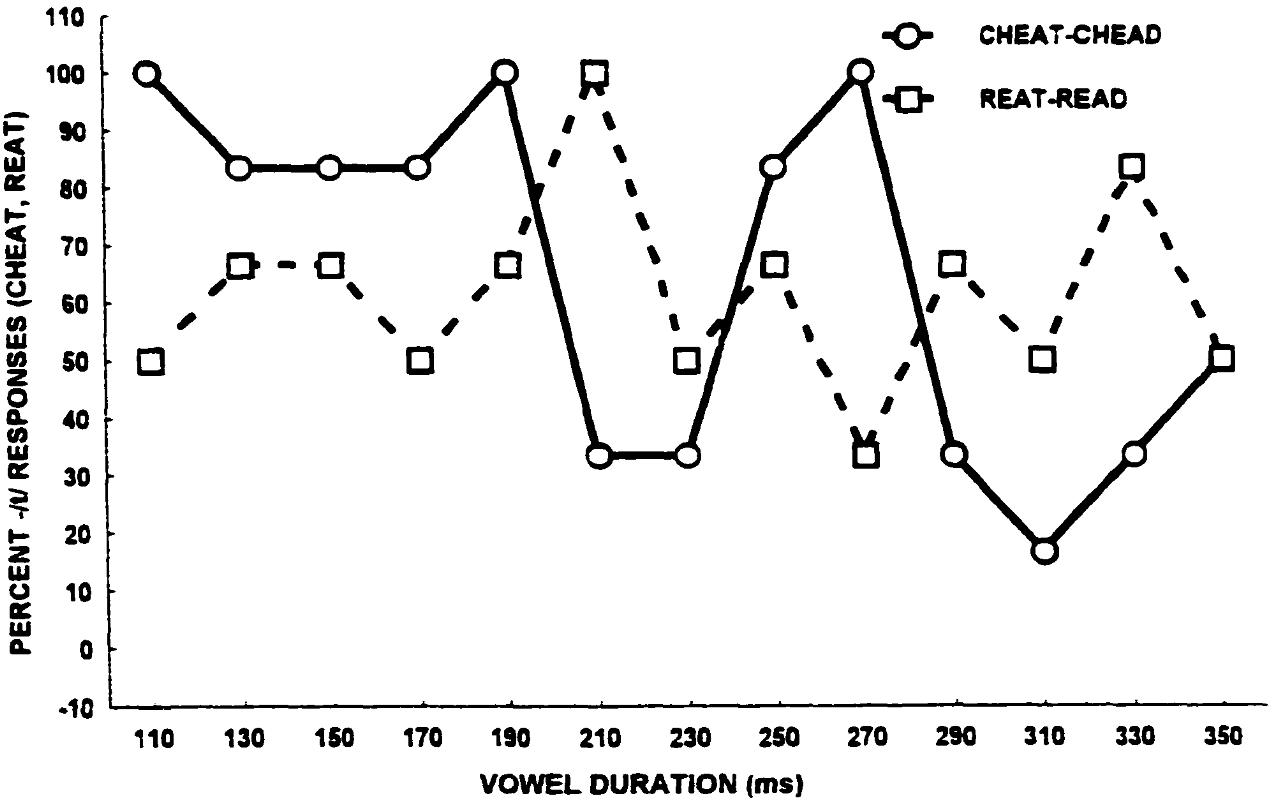
FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350



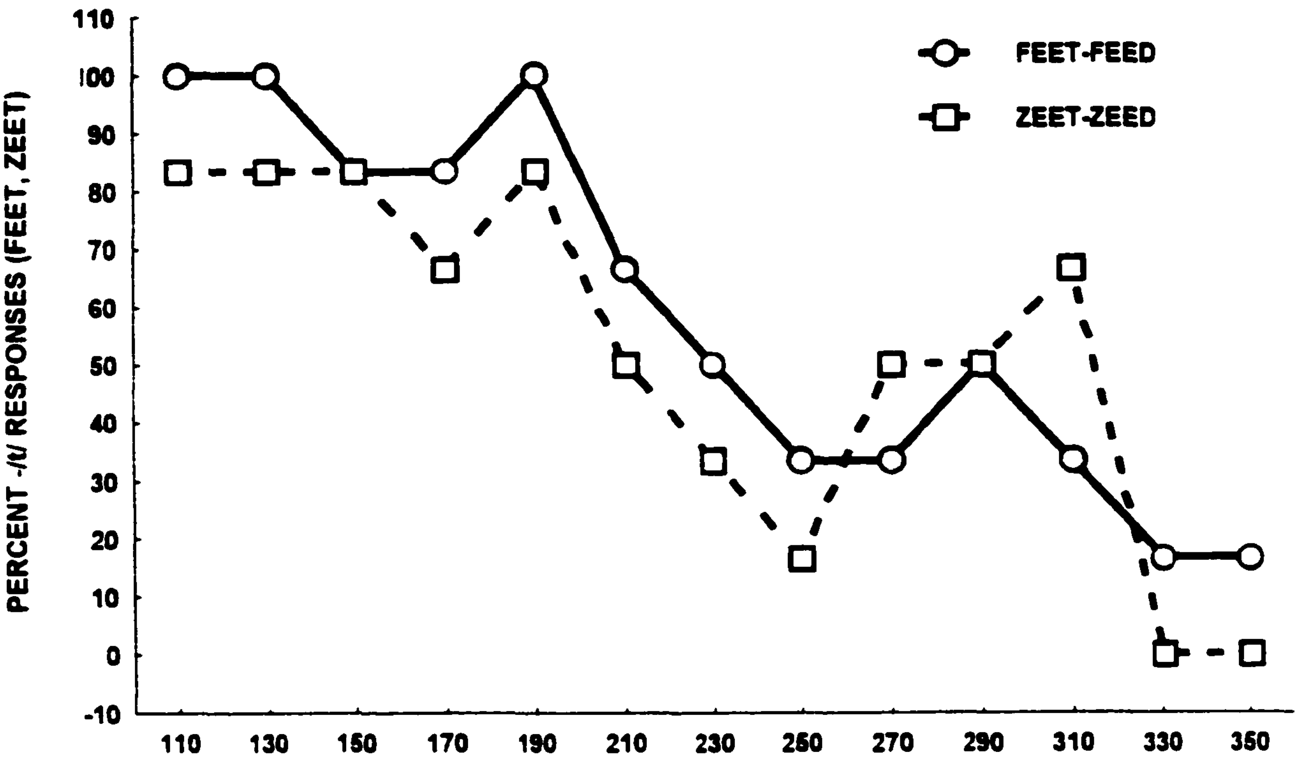
CHEAT-CHEAD
REAT-READ
PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

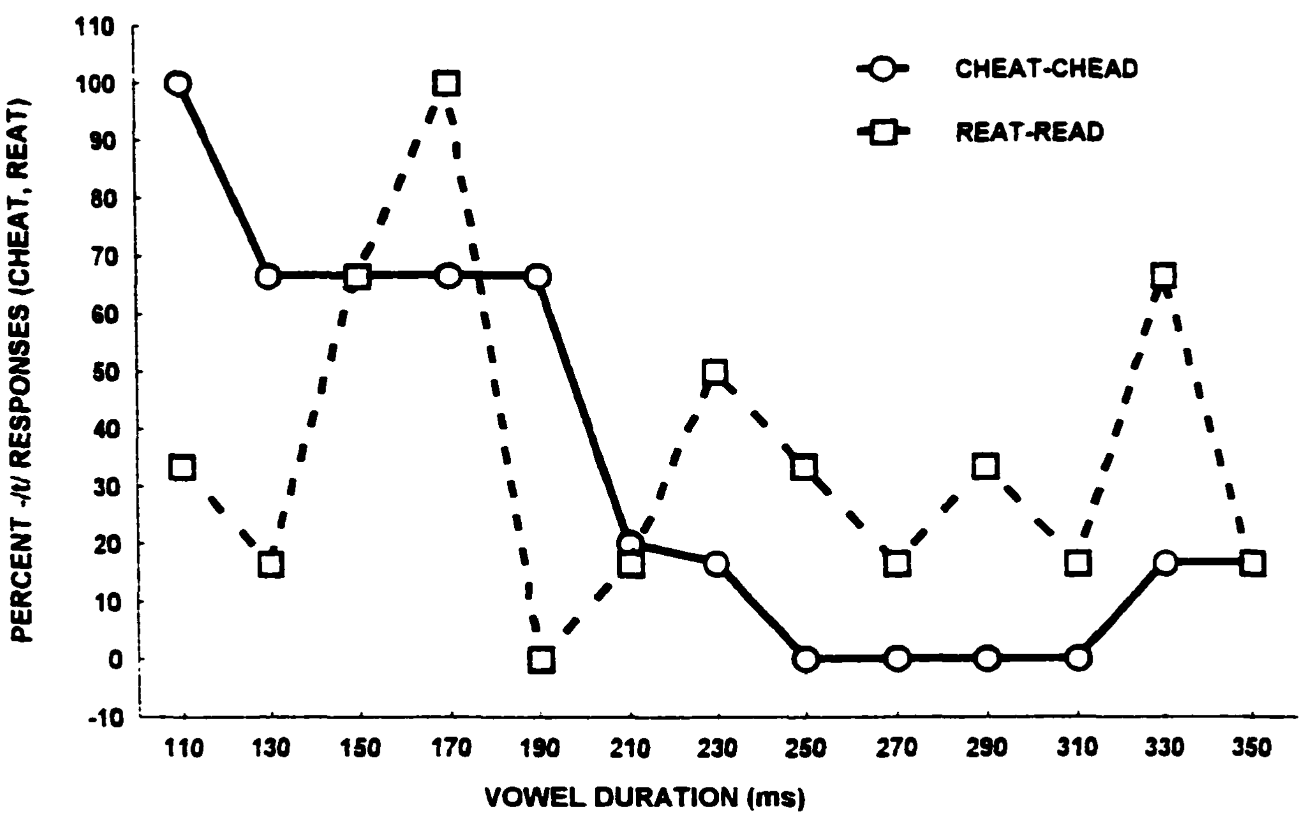
SLI#20


FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110 130 150 170 190 210 230 250 270 290 310 330 350


CHEAT-CHEAD
REAT-READ
PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110 130 150 170 190 210 230 250 270 290 310 330 350
VOWEL DURATION (ms)

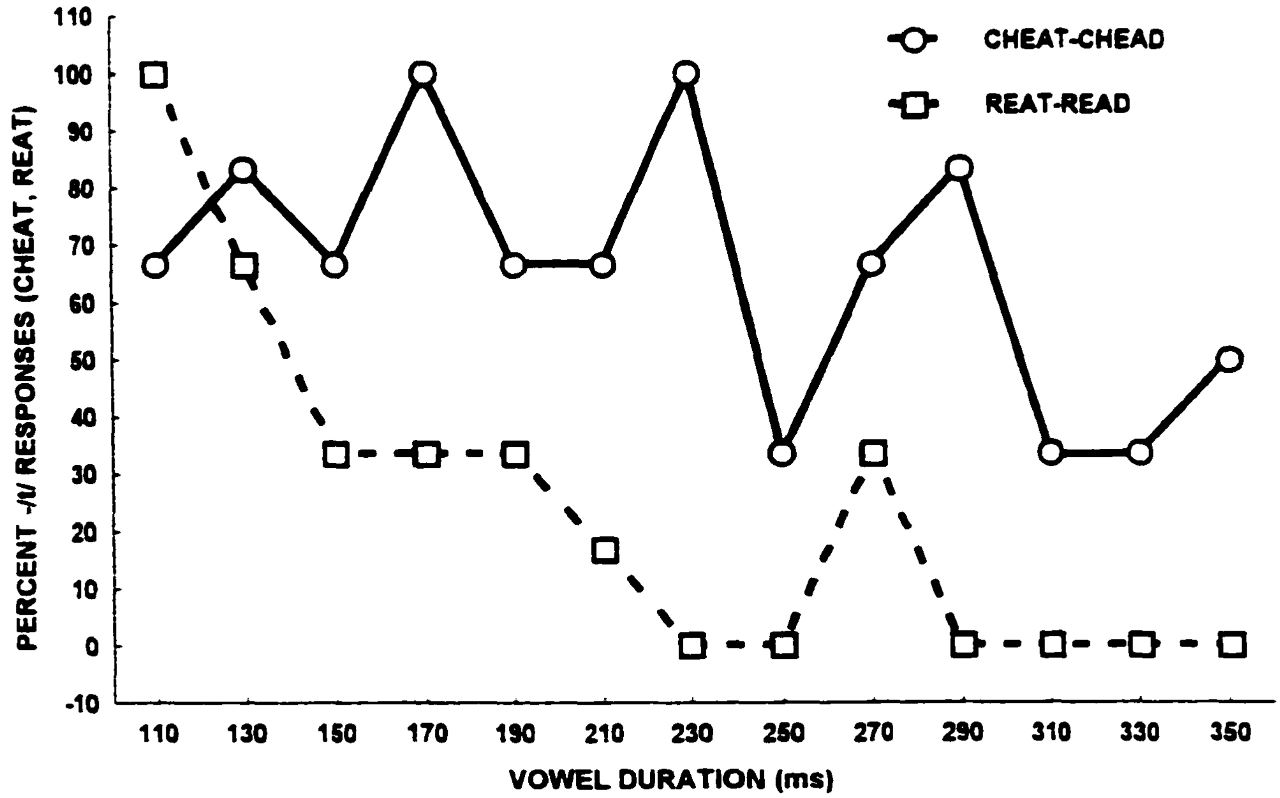
SL#21


FEET-FEED
ZEET-ZEED
PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350

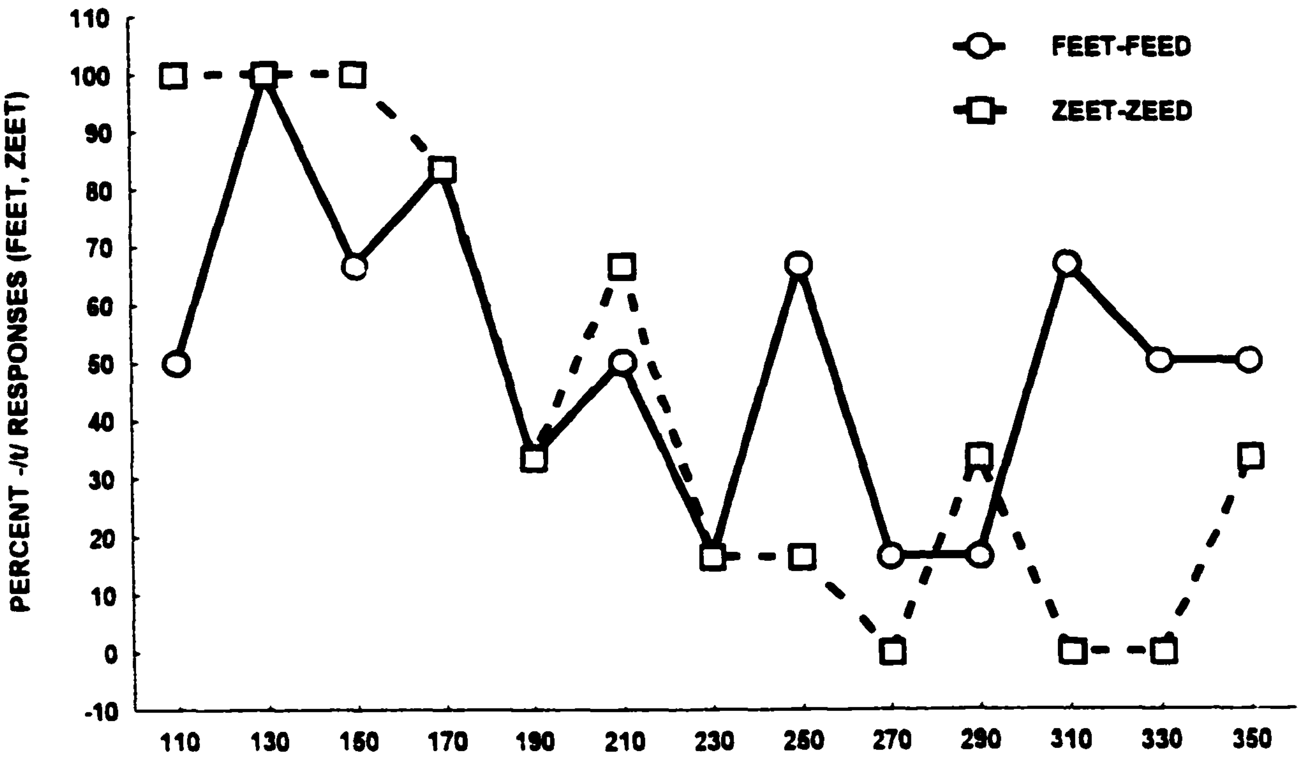

CHEAT-CHEAD
REAT-READ
PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

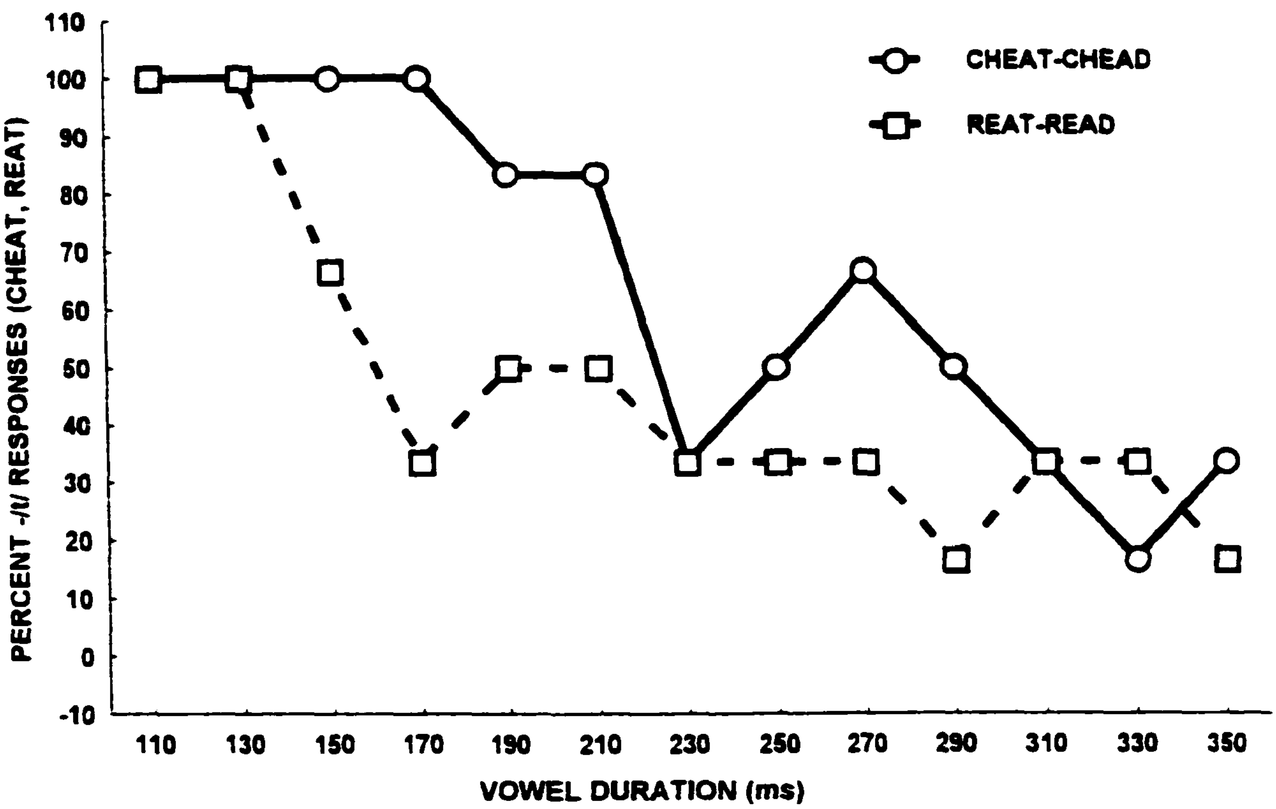
SL#26


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

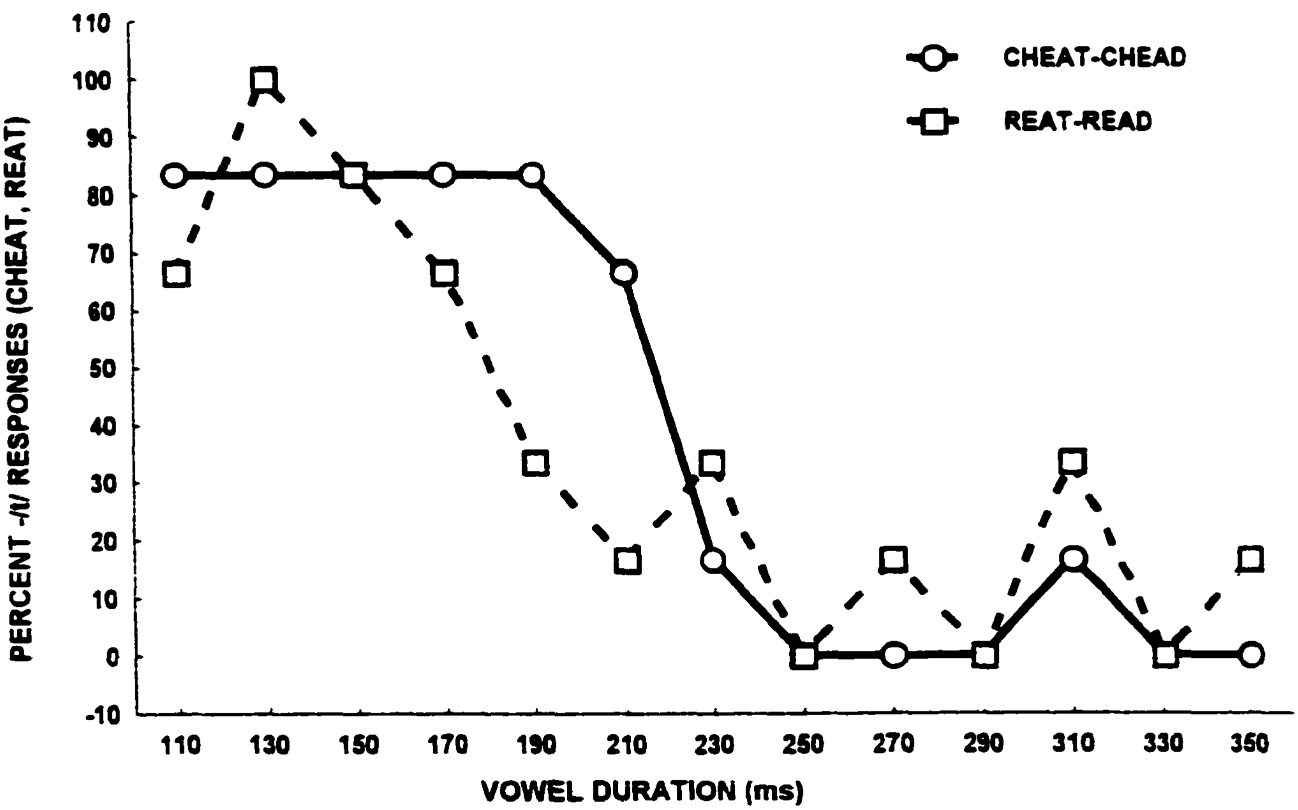
SLI#27


PERCENT -/t/ RESPONSES (FEET, ZEET)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
FEET-FEED
ZEET-ZEED

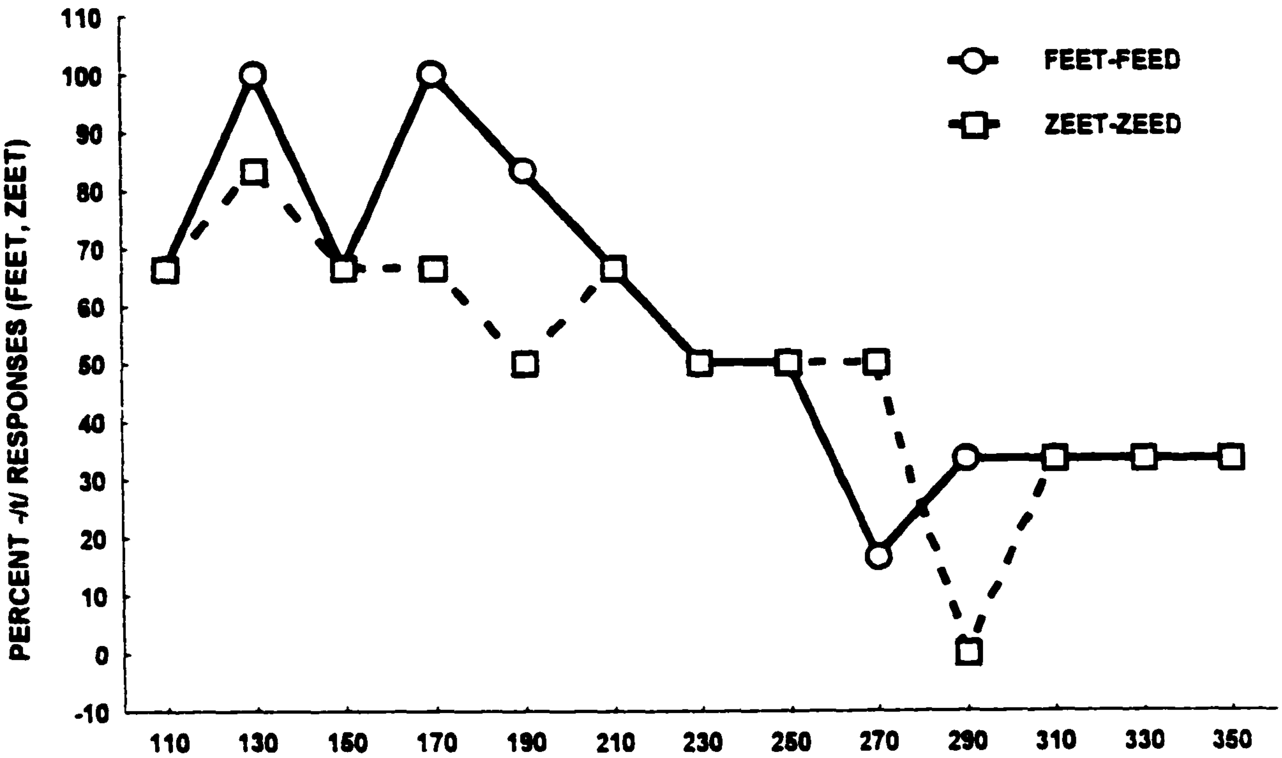

PERCENT -/t/ RESPONSES (CHEAT, REAT)
110
100
90
80
70
60
50
40
30
20
10
0
-10
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)
CHEAT-CHEAD
REAT-READ

SLI#29

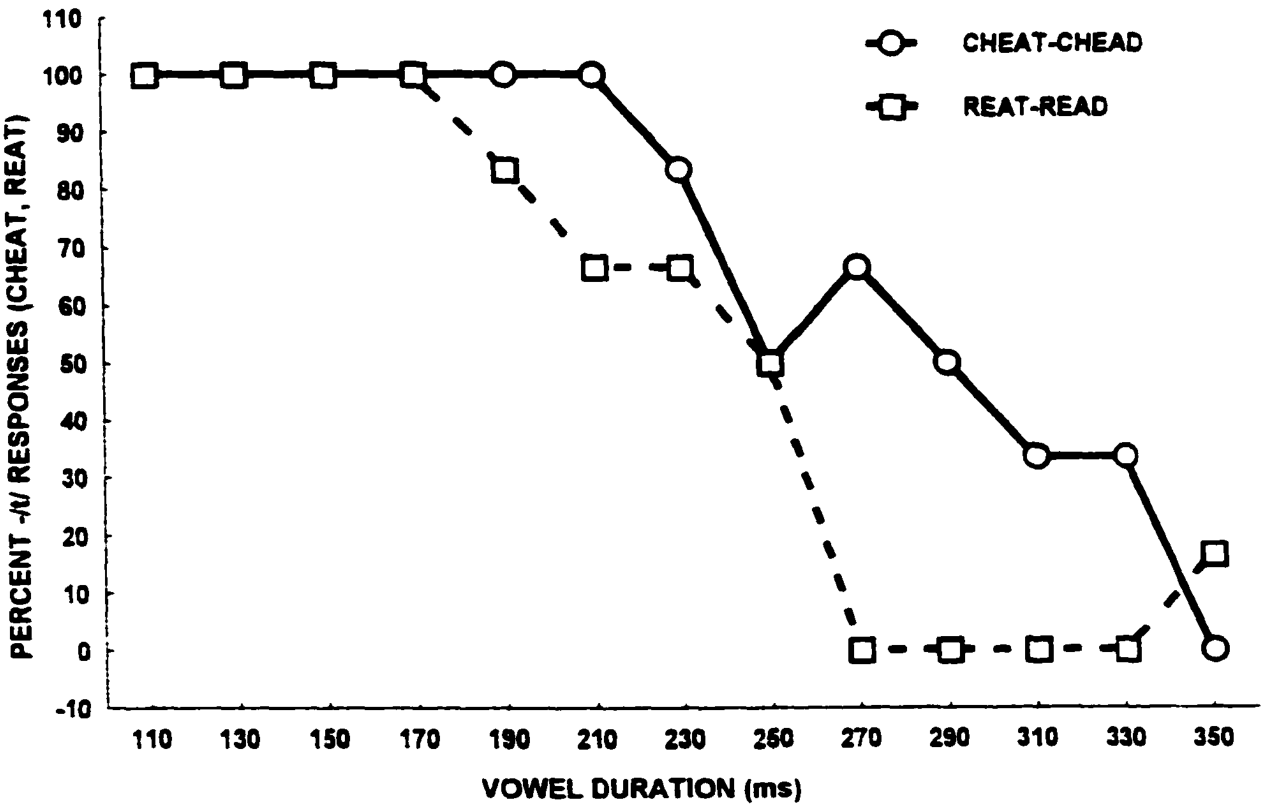

110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350


110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

SLI#30



110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (FEET, ZEET)
FEET-FEED
ZEET-ZEED
110
130
150
170
190
210
230
250
270
290
310
330
350



110
100
90
80
70
60
50
40
30
20
10
0
-10
PERCENT -/t/ RESPONSES (CHEAT, REAT)
CHEAT-CHEAD
REAT-READ
110
130
150
170
190
210
230
250
270
290
310
330
350
VOWEL DURATION (ms)

Appendix F

Observed category boundaries for individuals (shortest vowel duration at or near 50%)

	Continuum			
Participant # by group	Word-Nonword CHEAT-CHEAD	Nonword-Word REAT-READ	Word-Word FEET-FEED	Nonword-Nonword ZEET-ZEED
TLD				
4	190	170	150	190
5	230	110	190	290
8	310	230	270	250
12	250	250	250	250
13	230	150	230	190
15	230	190	210	230
18	190	230	190	330
22	250	230	250	310
32	210	170	250	150
33	250	230	250	210
35	270	210	230	230
36	250	190	230	190
37	230	110	310	210
SLI				
7	NONE	210	250	110
10	170	110	150	150
11	190	150	170	170
14	230	130	150	190
17	210	130	130	210
19	210	110	190	170
20	210	110	270	150
21	250	150	230	210
26	250	150	250	210
27	230	170	110	190
29	230	190	230	250
30	250	250	230	190

Appendix G

Comparisons of TLD and SLI mean category boundaries* and areas of uncertainty* for all four continua. Predicted values based on linear regression analysis (observed boundaries in parentheses as reported in Table 4.)

	Stimulus Condition			
	Word - Word FEET-FEED	Nonword - Nonword ZEET - ZEED	Word - Nonword CHEAT-CHEAD	Nonword-Word REAT-READ
Predicted (Observed) Category Boundary*				
TLD	239 (231.5)	256 (233.1)	234 (237.7)	217 (190)
SLI	228 (196.7)	227 (183.3)	250 (210.9)	188 (155)
t-value	1.49 (1.83)	3.24 (2.81)	2.23 (1.33)	3.03 (1.98)
p	.09 (.04)	.001 (.006)	.03 (.09)	.003 (.03)
Predicted Area of Uncertainty*				
TLD	158 - 319	154 - 358	155 - 312	110 - 325
SLI	147 - 308	125 - 329	171 - 328	80 - 296

*Measured in vowel duration (ms)

Tests of significance for linear regression results for each linguistic condition identification slope, and for each area of certainty and uncertainty. T-tests (df=1) examining the effects of group on regression slopes

Linguistic condition	Vowel duration range	Parameter Estimate $(Slope_{HD} - Slope_{SH})$	Standard Error	t- value	p- value
CHEAT-CHEAD	110-350MS	0.06031	0.02707	2.23	0.0266
	110-170MS	0.06026	0.02601	2.32	0.0226
	190-270MS	0.05667	0.05425	1.04	0.2983
	290-350MS	0.18542	0.04437	4.18	<.0001
ZEET-ZEED	110-350MS	0.08675	0.02679	3.24	0.0013
	110-170MS	0.15507	0.03494	4.44	<.0001
	190-350MS	0.05639	0.03514	1.60	0.1100
REAT-READ	110-350 ms	0.08276	0.02735	3.03	0.0027
	130-330MS	0.08790	0.03072	2.86	0.0045
FEET-FEED	110-350MS	0.04058	0.02719	1.49	0.1366
	110-190MS	0.09944	0.03606	2.76	0.0067
	190-290 ms	0.05958	0.04487	1.33	0.1863

Reference List

American Speech Language Hearing Association (1990). Standard for hearing screening in school-age children. *Supplement 32* as noted in Grason-Stadler, Inc. (October, 1996). *GSI 38 Auto tymp instruction manual 1738-0100, Rev.5.*

American National Standards Institute (1989). *Specifications for audiometers [ANSI S3.6-1989].* New York: American National Standards Institute.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105,* 158-73.

Bishop, D., Carylon, R., Deeks, J., & Bishop, S. (1997). Auditory temporal processing impairment: Neither necessary nor sufficient for causing language impairment in children. *Journal of Speech, Language, Hearing Research, 42,* 1295-310.

Brady, S. (1998). *A close look at the science behind Fast ForWard.* Paper presented at the American Speech Language Hearing Association (ASHA) convention, November, 1998. San Antonio, TX.

Bradlow, A., Kraus, N., Nicol, T., McGee, T., Cunningham, J., Zecker, S., Carrell, T. (1999). Effects of lengthened formant transition duration on discrimination and neural representation of synthetic CV syllables by normal and learning-disabled children. *Journal of the Acoustical Society of America, 106,* 2086-2096.

Brinton, B., Fujiki, M., & McKee, L. (1998). Negotiation skills of children with specific language impairment. *Journal of Speech, Language, Hearing Research, 41*, 927-940.

Brown, L., Sherbenou, R., & Johnsen, S. (1997) *Test of Nonverbal Intelligence-3 (TONI-3)*. Circle Pines, MN: American Guidance Service

Burton, M W., Baum, S. R., & Blumstein, S. E. (1989). Lexical effects on phonetic categorization of speech: the role of acoustic structure. *Journal of Experimental Psychology in Human Perceptual Performance, 15*, 567-75.

Carroll, J. B., Davies, P., & Richman, B. (1971) *Word Frequency Book*. NY: Houghton Mifflin Co.

Catts, H. (1993). The relationship between speech-language impairments and reading disabilities. *Journal of Speech, Language, Hearing Research, 36*, 948-958

Cleave, P. & Rice, M. (1997) An examination of the morpheme BE in children with specific language impairment: The role of contractibility and grammatical form class. *Journal of Speech, Language, Hearing Research, 40*, 480-492.

Connine, C. M., & Clifton, C. (1987). Interactive use of lexical information in speech perception. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 291-299

Connell, P. & Stone, C.A. (1992). Morpheme learning of children with specific language impairment under controlled instructional conditions. *Journal of Speech and Hearing Research, 35*, 844-852.

Dollaghan C., & Campbell, T. (1998) Nonword repetition and child language impairment. *Journal of Speech Language Hearing Research, 41*, 1136 - 46.

Edwards, J., & Lahey, M. (1996). Auditory lexical decisions of children with specific language impairment. *Journal of Speech and Hearing Research, 39*, 1263-73.

Elliot, L.L., & Hammer, M. (1988). Longitudinal changes in auditory discrimination in normal children and children with language learning problems. *Journal of Speech and Hearing Disorders, 53*, 467-474

Fazio, B (1997) Memory for rote linguistic routines and sensitivity to rhyme: A comparison of low-income children with and without specific language imapairment. *Applied Psycholinguistics, 18*, 345-372

Fox, R. (1984). Effect of lexical status on phonetic categorization. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 526-540.

Frumkin, B., & Rapin, I. (1980). Perception of vowels and consonant-vowels of varying duration in language impaired children. *Neuropsychologia*, 18, 443-453.

Ganong, W (1980) Phonetic categorization in auditory word perception. *Journal of Experimental Psychology: Human Perception and Performance, 6*, 110-125

Gathercole, S., & Baddeley, A. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29*, 336-360.

Greenlee, M. (1980). Learning the phonetic cues to the voiced-voiceless distinction: A comparison of child and adult speech perception. *Journal of Child Language, 7*, 459-468.

Hodson, B., & Paden, E. (1981). Phonological processes which characterize unintelligible and intelligible speech in early childhood. *Journal of Speech and Hearing Disorders*, 46, 369-373

Hollingshead, A. (1975). Four factor index of social status: working paper. Acquired from the University of Pennsylvania Libraries.

Kent, R. (1992). The biology of phonological development. In C. A. Ferguson, L. Menn, & C. Stoel-Gammon (Eds.), *Phonological development: Models, research, implications*. Timonium, MD: York Press

Krause, S. E. (1982). Developmental use of vowel duration as a cue to postvocalic stop consonant voicing. *Journal of Speech and Hearing Research, 25*, 388-393

Kuhl, P. K. (1991). Perception, cognition and the ontogenetic and phylogenetic emergence of human speech. In S. E. Brauth, W. S. Hall, and R.J. Dooling, (Eds.). *Plasticity of Development*. (pp.73-106). Cambridge, MA. MIT Press.

Lahiri A., & Marslen-Wilson W. (1991). The mental representation of lexical form: a phonological approach to the recognition lexicon. *Cognition, 38*, 245-94

Leonard, L. (1989). Language learnability and specific language impairment in children. *Applied Psycholinguistics, 10*, 179-202

Leonard, L B. (1998). *Children with specific language impairment*. Cambridge, MA: The MIT Press.

Leonard, L., McGregor, K., & Allen, (1992). Grammatical morphology and speech perception in children with specific language impairment. *Journal of Speech & Hearing Research, 35*, 1076-1085.

Mayer-Johnson Company. (1998) Boardmaker for windows [Computer software]. Solana Beach, CA.

McQueen, J M (1991). The influence of the lexicon on phonetic categorization: stimulus quality in word-final ambiguity. *Journal of Experimental Psychology in Human Perceptual Performance, 17*, 433-43.

Miller, J.L. (1994) On the internal structure of phonetic categories: a progress report. *Cognition, 50* 271-85

Mody, M., Studdert-Kennedy, M., & Brady, S (1997). Speech perception deficits in poor readers: auditory processing or phonological coding? *Journal of Experimental Child Psychology 64*, 199-231.

Moe, A J., Hopkins, C J., & Rush, R T (1982). *The Vocabulary of First-Grade Children*. Springfield, IL. Charles C. Thomas.

Montgomery, J (2002). Understanding the language difficulties of children with specific language impairments: Does verbal working memory matter? *American Journal of Speech-Language Pathology*, 11, 77-91

Nygaard, L. C., & Pisoni, D B. (1995). Speech Perception: New directions in research and theory. In J.L. Miller, and P D Eimas (Eds.) *Speech, Language, and Communication* (pp 63-96).New York, NY: Academic Press.

Plante, E. (1998). Criteria for SLI: The Stark and Tallal legacy and beyond. *Journal of Speech, Language, and Hearing Research 41*, 951-957.

Psychology Software Tools, Inc., (1999) E-Prime [Computer software] http://www.pstnet.com

Raphael, L. J. (1972). Preceding vowel duration as a cue to the perception of voicing of American English consonants in word-final position. *Journal of the Acoustical Society of America (51)*, 1296-1303

Semel, E., Wiig, E., & Secord, W. (1995). *Clinical Evaluation of Language Fundamentals 3 (CELF-3)*. San Antonio, TX: The Psychological Corporation

Sendlmeier, W. (1995) Feature, phoneme, syllable or word. How is speech mentall represented? *Phonetica, 52*, 131-143

Stark, R. E., & Heinz, J. M. (1996). Vowel perception in children with and without language impairment. *Journal of Speech and Hearing Research 39*, 860-869

Stark, R. E., & Tallal, P. (1981) Selection of children with specific language deficits *Journal of Speech and Hearing Disorders, 46*, 114-122.

Storkel H. L. (2001). Learning new words: phonotactic probability in language development. *Journal of Speech Language Hearing Research, 44*, 1321-37

Studdert-Kennedy, M., Liberman, A. M., Brady, S. A., Fowler, A. E., Mody M., & Shankweiler, D. P. (1994). Lengthened Formant Transitions are Irrelevant to the Improvement of Speech and Language Impairments. *The Haskins Laboratories Status Report on Speech Research, 119*, 35-38.

Sussman, J. E. (1993). Perception of formant transition cues to place of articulation in children with language impairments. *Journal of Speech and Hearing Research, 36,* 1286 - 1299.

Syntrillium Software Corporation. (1997). Cool Edit Pro [Computer software] Phoenix, AZ

Tallal, P. (1976). Rapid auditory processing in normal and disordered language development. *Journal of Speech and Hearing Research, 19,* 561-571

Tallal, P., Miller, S., & Fitch, R. (1993). Neurobiological basis of speech: A case for the preeminence of temporal processing. In P Tallal, A. M. Galaburda, R.R. Llinas & C. von Euler (eds), *Temporal Information Processing in the Nervous System: Special Reference to Dyslexia and Dysphasia. Annals of the New York Academy of Sciences, 682* 27-47

Tallal, P., & Piercy, M. (1973a). Defects of non-verbal auditory perception in children with developmental aphasia. *Nature, 241,* 468-9

Tallal, P., & Piercy, M. (1973b). Developmental aphasia. Impaired rate of nonverbal processing as a function of sensory modality. *Neuropsychologia, 11,* 389-398.

Tallal, P., & Piercy, M. (1974). Developmental aphasia: Rate of auditory processing and selective impairment of consonant perception. *Neuropsychologia, 12,* 83-93.

Tallal, P., & Piercy, M. (1975). Developmental aphasia. The perception of brief vowels and extended stop consonants. *Neuropsychologia, 13,* 69-74.

Tallal, P., & Stark, R. (1981). Speech acoustic cue discrimination abilities of normally developing and language impaired children. *Journal of the Acoustical Society of America 69*, 568-574.

Tallal, P., Stark, R. E., Kallman, C., & Mellits, D. (1980). Perceptual constancy for phonemic categories: a developmental study with normal and language impaired children. *Applied Psycholinguistics, 1*, 49-64.

Tallal, P, Stark, R E., Kallman, C., & Mellits, D (1981) A reexamination of some nonverbal perceptual abilities of language-impaired and normal children as a function of age and sensory modality. *Journal of Speech and Hearing Research, 24*, 351-357