To the Graduate Council

I am submitting herewith a thesis written by Susan Lynne Pursell entitled "Boundary of steady-state synthetic vowels [ɪ] and [ɛ] in adults and school-age children" I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Speech Pathology

Lori A Swanson, Major Professor

We have read this thesis
and recommend its acceptance

Accepted for the Council

Associate Vice Chancellor and
Dean of the Graduate School

BOUNDARY OF STEADY STATE SYNTHETIC VOWELS [ɪ] AND [ɛ] IN ADULTS AND SCHOOL-AGE CHILDREN

A Thesis
Presented for the
Masters of Arts
Degree
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Susan Lynne Pursell
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DEDICATION

Ever sınce I was a child, I have wanted to fly This thesis is dedicated to those who helped me achieve my dream, my parents, who encouraged me to spread my wings, my husband and daughters who have graciously allowed me the time to fly, Lori Swanson, who mapped out my flight plan, and most importantly, God who gives each of us a beautiful sky The view ıs spectacular!

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ABSTRACT

The purpose of this study was to investigate the categorical perception skills of typically developing school-age children and adults using synthetic vowels [ɪ] and [ɛ] Participants included ten adults, ten 5- to 6-year-old children, and ten 10-year-old children Participants listened to 14 variants or tokens on a continuum between [ɪ] and [ɛ] presented 10 times each for a total of 140 test trials. Upon presentation of each stimulus, participants were asked to choose between the two vowels Percentage of each token identified as [ɪ] was calculated for each of the 14 variants for each subject The boundary, location of the 50% response point, was identified and steepness of the slope at the boundary was calculated Comparisons of variance for each measure were made among groups No significant difference in boundary was found among groups However, a significant difference in slope at the boundary was found between the younger children and adults A general trend was noted that slope at the boundary got steeper as age progressed These findings support previous reports (e g , Walley & Flege, 1999) suggesting that categorical perception skills become more efficient as children mature

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CHAPTER I

Introduction and Review of the Literature

Introduction

Categorical perception is a model which addresses several factors important in vowel perception According to this model, a perceptual space for each vowel exists When a vowel is perceived, it is compared to memory structures of categories to facilitate accurate perception Categorical perception can be achieved by either relating an incoming stimulus to a token at the center of the vowel space or to anchors at the boundary of the vowel space (Sussman & Gekas, 1997)

Related to categorical perception is the perceptual magnet effect. According to proponents of this model, all speakers of a native language have a prototype of the best exemplar of each vowel in memory storage When an auditory stimulus is presented, it is drawn to one of the prototypes and perceived as that prototype Thus, when sounds are spectrally similar to prototypes, variability in discrimination of the two sounds is minimal However, when sounds are located at a categorical boundary, variability in discrimination between the sounds and prototypes is maximal (Kuhl, 1991)

Vowel perception has been investigated in children and infants Research has shown that 6-month-old infants categorize variants of vowel prototypes that are distal to one another a high front vowel and a high back vowel (Grieser & Kuhl, 1989) The use of vowel categorization has also been shown in infants as young as 2 months with stimuli that are spectrally dissimilar, [i] and [a] (Marean, Werner, & Kuhl, 1992) Ohde, Haley, and McMahon (1996) investigated the development of vowel perception of acoustically similar vowels using consonant-vowel constructs Their findings indicate that young school-age children (5-year-olds) exhibit difficulty when identifying vowels with short duration and in certain CV contexts Eleven-year-old children exhibited the same patterns of identification as adults Additionally, vowel perception of 3- and 4-year-old children was examined (Ohde & Haley, 1997) Two types of stimuli were used vowels with moving transitions and vowels with straight transitions A difference between groups (3-year-old children and 4-year-old children) was noted in identification rates when vowels differed in duration· vowel identification rate increased with increasing stimulus durations Investigations have also shown that vowel perception becomes more efficient as children near 10 years of age (Walley & Flege, 1999)

The studies previously mentioned have examined vowel perception as a developmental process related to duration and formant transitions. Using one tense vowel and one lax vowel, Walley and Flege (1999) examined categorical perception in children and adults Findings indicate that categorical perception improves as listeners advance in age Categorical perception between two lax vowels has yet to be tested in children This could be accomplished by modeling the research paradigm described by Náběelek, Czyzewski, and Crowley (1993), using variants on a continuum between two lax vowels adjacent to one another in the vowel space The present investigation attempts to identify the categorical boundary exhibited by children, 5- to 6- and 10-years of age, between acoustically similar vowels (i e , high front vowels adjacent to one another in perceptual vowel space) By comparing the variance of boundaries between the two groups of children and a group of adults, the author examines the use of categorical perception as a developmental process

Review of the Literature

Approaches to Vowel Perception Research

Vowel perception research has traditionally been approached in two distinct manners Strange (1989) differentiates and defines these two approaches The first emphasizes the role of static inherent characteristics of the intended vowel and the second emphasizes not only the coarticulatory effects of neighboring phonemes but also the spectral change characteristics present within the vowel Strange refers to the former of these approaches as elaborated target model and the latter as dynamic specification

Elaborated target model The elaborated target model suggests that perception of vowels is based on static acoustic parameters of individual sounds These static parameters include steady state formant frequencies, fundamental frequencies, and the relational properties between the former parameters (Neary, 1989) Using these parameters, categorical perception of vowels has been investigated (Hillenbrand, Getty, Clark, & Wheeler, 1995) Additionally, centers of these vowel spaces have been identified and investigated (Marean, Werner, & Kuhl, 1992) Using the elaborated target model, Kuhl (1991) proposed a model in which each vowel is represented by a prototype which functions as a magnet, drawing acoustically similar stimuli to the prototype Hence, differences among similar tokens become minimized Tokens at the edge of the vowel space, the categorical boundary for the specific acoustic signal, have a greater variance in listener identification than those near the prototype Therefore, differences between distinct tokens become maximized Categorical perception and the perceptual magnet effect will be discussed in more detail under separate headings.

Dynamic specification model An alternate approach to vowel perception research emphasizes the role of coarticulatory events extrinsic to the vowel and the effects of spectral change intrinsic to the vowel The dynamic specification model addresses the role of these dynamic sources of information Investigations of the effects of coarticulatory events on vowel perception have focused on vowels embedded in consonant-vowel (CV), consonant-vowel-consonant (CVC), and vowel-consonant (VC) constructs (Andruski & Neary, 1992, Neary, 1989, Ohde, Haley, & McMahon, 1996) Using this model, research in perception of vowels using both natural and synthetic speech has been conducted

Using natural speech stimuli and following the dynamic specification model, Gottfried and Strange (1980) compared identification rates of vowels spoken in isolation versus vowels spoken in CVC contexts Stimuli consisted of vowels spoken by three adult female and three adult male talkers Vowels were recorded spoken in isolation and in the following constructs, /bVb/, /pVp/, /gVg/, /gV/, /Vg/, /kVk/, /kV/, and /Vk/ The findings suggest that vowels produced in labial context (i e , /pVp/, and /bVb/) were more accurately identified than vowels produced in isolation Results from identification rate of /k/- and /g/- constructs reveal similar results Further, the findings reveal a higher identification rate of tense vowels than lax vowels Finally, the authors note that there was a significant interaction between front vowels (i e , /i, ɪ, e, ɛ, æ/) and context condition (i e , more errors were made on front vowels when produced in /gVg/ and /Vg/ contexts than /gV/ context or in isolation) The authors postulate that this may be due to constraints of the English language.

Synthetic stimuli have also been used following the dynamic specification model Ohde and Haley (1997) used synthetic stimuli to investigate the effects of short duration stimulus onsets on vowel perception in adults, 3-year-old children, and 4-year-old children The stimuli used were comprised of CV syllables (i e , [d, g] followed by [i, u, a]) synthesized using Klatt's cascade/parallel formant synthesizer The results indicated that vowel perception is developmental For the /dV/ syllables, perception was influenced by age of subject, type of transition (i e , either moving or straight transitions), and stimulus length (i e , 10, 30, or 46 ms) For /dV/ syllables, the adults and 4-year-old children scored significantly higher in vowel identification than the 3-year-old children The adult participants scored the highest Furthermore, /dV/ syllables with moving transitions at longer durations (i e , 30 and 46 ms) had a higher rate of identification than syllables with straight transitions These phenomena were not noted in /gV/ syllables As with the /dV/ syllables, straight transitions of vowels produced in /gV/ syllables yielded more variability in responses than moving transitions In this set of stimuli, participant's age and voicing duration were the main effects noted

Andruski and Neary (1992) used both natural and synthetic stimuli to investigate the role of vowel-inherent spectral change in vowel perception Initially, they used natural stimuli spoken by three female and three male speakers of Western Canadian English The speakers produced 10 vowels in a /bVb/ context Their results indicate that vowels produced in this CVC context have the same formant movement that is seen in vowels produced in isolation The authors suggest that dynamic transitional information, resulting from coarticulatory effects of adjacent consonants, may not be necessary for appropriate vowel identification To test their theory, the researchers conducted an investigation using stimuli with the acoustics of the vowel centers removed thus producing "silent centers " They used syllables spoken by two female and two male speakers The stimuli were then altered using computer programming that allowed the researchers to insert 150 ms of silence in the center of the syllable while removing formants of the vowels Forty ms head and tail sections remained The 40 ms head section consisted of 30 ms of voicing following the initial burst for the /b/ followed by 10 ms of transition The final 40 ms consisted of the reverse (i e , 10 ms of transition followed by 30 ms of voicing leading up to the final closure) Isolated vowels were produced using a similar method (i e , the head consisted of 20 ms onset followed by 10 ms of transition and the tail consisted of the reverse) The results of this investigation suggest that vowel margins provide enough information for appropriate identification. In an attempt to replicate and extend their findings, the authors repeated the latter investigation using synthetic stimuli CVC constructs of /bVb/ and vowels in isolation were synthesized using the Klatt synthesizer The resulting findings suggest that listeners were able to identify vowels produced both naturally and synthetically by using information available in the centers of the vowels, in the transition of the vowels (i e , stimuli with silent centers), or in the presence of full coarticulation in CVC constructs The authors reported that adding the information from coarticulation does not improve the rate of identification

Silent centers have also been used with a dynamic specification model to investigate stimuli presented in degraded listening conditions (Hura, 1994) Her results reveal that, although appropriate vowel perception may be possible in the absence of the vocalic nuclei, in the presence of noise, identification rates were higher for vowels produced in full coarticulation and in isolation than for vowels produced with silent centers Thus, in degraded listening conditions, vocalic nuclei provide essential information for appropriate identification of the acoustic signal

Some researchers have included both elaborated target and dynamic specification approaches in their investigations Neary (1989) investigated the parameters which facilitate perception of vowels in both isolation and in CVC constructs The purpose of his investigation was to identify the properties that facilitate vowel perception. His work addressed factors including the role of both intrinsic and extrinsic factors in vowel perception, context dependent effects, and vowel-inherent dynamic factors Intrinsic factors which facilitate perception include fundamental frequency and higher formants (i e , F3, F4, and F5) The extrinsic factor evaluated was an ensemble of F1 X F2 Neary found a main effect of pitch and ensemble. Context dependent effects were measured using vowels in isolation and in CVC constructs (i e , /bVb/ and /dVd/) Stimuli were synthesized on three continua progressing from the Canadian vowel /ɒ/ through /ʌ/ and terminating on /ɛ/ Responses to tasks of identification of tokens on each continuum revealed similar categorical boundaries for each condition Vowel-inherent dynamic factors investigated included intrinsic duration and spectral change Neary's conclusion, based on his findings, is that all of these factors have a role in vowel perception and that a unified theory that accounts for all of these variables has yet to be established

Vowel perception research has taken many forms Both the elaborated target model and the dynamic specification model have been used to investigate factors which contribute to perception of vowels While vowels produced in consonantal contexts (Gottfried & Strange, 1980) and with moving transitions (Ohde & Haley, 1997) may yield the most accurate rate of identification, research has shown that information contained within the vocalic nuclei contains sufficient information to enable correct identification (Andruski & Neary, 1992). Using steady-state stimuli in isolation allows the researcher to have adequate control of the stimulus

Theories of Vowel Perception

Two categories of vowel perception have been identified (Rosner & Pickering, 1994) The first is referred to as "strong articulatory theories" Theories in this category consider the articulatory movements of the speaker and a synthesis of this information about movements in the listener Alternately, "strong auditory theories" are based entirely on the acoustic parameters contained within the stimulus itself

Strong articulatory theories Liberman and Mattingly (1985) proposed a revised motor theory of speech perception The first assumption of this theory is that the speech signal has a component of intended sequenced articulatory movements The second assumption is that there is a relationship between the acoustic signal and signal production Liberman suggests that perception does not originate in the acoustic parameters of the speech signal Instead, perception is achieved through an innate association of the acoustic signal and the directives needed to produce the signal Liberman labels these intended directives "gestures" In most speech, these gestures overlap and the signal may be influenced by several gestures simultaneously This accounts for the target undershoot phenomenon

Strong auditory theories Theories in this category rely strictly on the acoustic signal to facilitate perception Sussman (1986) proposed a neuronal model of vowel perception.

In this model, the acoustic wave of the vowel spectrum excites neurons along the basilar membrane The excitation patterns are detected by differential detector neurons which combine the signal into two formant fields (i e , F1/F2, F1/F3, and F2/F3) Higher order detector neurons relay the combined signal to "vowel normalization fields " Final vowel perception can be described as a gradual projection of axons from the vowel normalization fields to abstract representation fields Sussman suggests that this final area may be in the auditory association cortex Sussman's vowel perception model rests solely on the acoustic properties of the vowel spectrum that is received through the auditory canal.

Syrdal and Gopal (1986) present a model of vowel recognition Like Sussman (1986), their model is based on the auditory excitation patterns of English vowels "Vowels are represented by the auditory distance between formants and between the fundamental frequency and the first formant" (Syrdal & Gopal, 1986, p 1099)

Limitations of Theories of Vowel Perception

Several phenomena exist that add complexity to models of perception The first problematic phenomenon is speaker normalization Another concern for theorists of vowel perception, defined by Schouten and van Hessen (1992), is the fact that vowels produced in context of other phonemes fail to exhibit the same inherent characteristics as those produced in isolation This is referred to as target undershoot

Speaker normalization When vowels are produced by different speakers, the acoustic signal varies between the speakers Variances can even be detected when one speaker produces multiple productions of the same vowel However, the listener assimilates the acoustic signals and perceptually identifies the target sound This is referred to as speaker normalization To address the problem of speaker normalization, researchers have used the elaborated target approach to vowel perception (Syrdal & Gopal, 1986) Syrdal and Gopal used an /hVd/ context to identify a multidimensional auditory space for vowels defined by fundamental frequencies, and frequencies of the first three formants of the acoustic signal The /hVd/ context was used because previous research (Stevens & House, 1963) had shown that the centers of the vowels produced in this context contain steady-state vocalic nuclei that are unaffected by the neighboring phonemes. Two types of speaker normalization have been identified intrinsic and extrinsic specification (Neary, 1989).

Intrinsic specification. Neary (1989) describes intrinsic specification as normalization dependent upon acoustic information inherent to the vowel These vowel-inherent parameters which facilitate normalization include the fundamental frequency, the formant frequencies of the steady state portion of the vowel, and the combination of increases of the fundamental frequency and third formant frequency

Extrinsic specification Extrinsic specification as described by Neary (1989) refers to speaker normalization dependent upon information that is "spread across a speaker's entire vowel system" (p 2088) Thus, speaker normalization is accomplished through distribution of information across all of the vowels within a single speaker's perceptual repertoire Addressing vowel normalization, Ryalls (1996) eliminates a visual component to speaker normalization which may be an extrinsic factor While some may suggest that visual information about the size of the speaker aids normalization, Ryalls points out that normalization occurs not only when people speak face to face but also during conversations using telephones

Target undershoot When vowels are produced in the context of other phonemes, a second problem arises that vowel-perception theorists must address In coarticulatory events, effects of pre-vocalic or post-vocalic phonemes alter the production of the vowel Many times, the formant frequencies produced in context of other phonemes do not equate the formant frequencies produced when a vowel is produced in isolation Often, the productions in phonemic context fall short of the productions in isolation This is referred to as target undershoot Valid theories of vowel perception must address target undershoot This is often accomplished by using the dynamic specification approach to vowel perception Even though vowels produced in CVC constructs fail to match the acoustic parameters of vowels in isolation, Gottfried and Strange (1980) found that vowels produced in CVC constructs were easier to identify than were vowels produced in isolation However, some researchers (Assman, Neary, & Hogan, 1982, Rakerd, Verbrugge, & Shankweiler, 1984) have found that identification rates for the two conditions of vowels were equal Thus, these findings suggest that the target undershoot phenomenon does not affect identification rate of vowels

Valid theories of vowel perception must address both target undershoot and normalization If vowels produced in natural speech in a variety of contexts are readily identified by listeners, then perception of vowels must be based on several factors and not limited to a single component

Perceptual Magnet Effect

Kuhl (1991) suggests that perception of vowels may be affected by a perceptual magnet effect Each vowel in a language has a perceptual prototype in the vowel space for the native speakers of that language When a listener hears a vowel that approximates his prototype, he assimilates the variances in the acoustic signal to that of the prototype Thus, stimuli that are close to the prototype are difficult to discriminate from the prototype Kuhl (1991) established a large set of synthetic tokens for [i] based on Peterson and Barney's data (1952) These tokens were presented to participants who rated the "goodness" of each token as a prototypical [i] From the data gathered, a prototype token and non-prototype token were defined Using these two tokens as hubs, Kuhl synthesized 32 variants around each center varying in the frequencies of the first and second formants Tokens were then presented to adult listeners who rated each token on a scale of one to seven· one representing a poor exemplar of [i] and seven representing the best exemplar of [i] Kuhl then used the token with the highest rating and defined it as the prototype for [i] She chose another token on the same vector distal from the prototype to serve as the non-prototype referent Participants listened to the referent followed by another stimulus They were instructed to press a button when the stimulus changed Listeners demonstrated less difficulty with the tasks when the referent was the non-prototype than when the referent was the prototype Kuhl defined this phenomenon as the "perceptual magnet effect "

Speech production is an ability unique to humans To investigate if the perceptual magnet effect is present in non-human primates, Kuhl (1991) tested for the presence of the effect in Rhesus monkeys She tested variants surrounding both a prototype condition and a non-prototype condition She found that the monkeys scored above chance level for both conditions However, the primates scored equally well on both the prototype condition and the non-prototype condition Therefore, the magnet effect was not demonstrated in the non-human species Kuhl (1991) further tested the effect ın 6-month-old infants She found that the ınfants' responses mirrored that of the adults previously described

To test the perceptual magnet theory, Lively and Pısoni (1997) used Kuhl's (1991) original stimuli and had adult participants assign a goodness rating to each Individual prototypes were defined based on the goodness ratings These prototypes with surrounding variants were synthesized for each participant Discrimination tasks requiring participants to label stimuli as same or different failed to support the perceptual magnet effect Furthermore, the findings indicate that changes in the second formant produced greater variability in discrımination than changes in the first formant frequency

Other researchers have attempted to replicate Kuhl's findings with mixed results Aaltonen, Eeoral, Hellstrom, Uusipaikka, and Lang (1997) tested the perceptual magnet effect with Finnish-speaking adults Their participants were classified as either "good" or "poor" categorizers based on findings from previous research The results obtained from the investigation of the perceptual magnet effect revealed that the effect was seen in participants labeled good categorızers but the effect was not found in the group labeled poor categorizers Perhaps the perceptual magnet effect was absent in poor categorızers because of their inefficient use of categories to aid perception Thus, they may have lacked a strong prototype as a referent for comparison

Frieda, Walley, Flege, and Sloane (1999) tested the perceptual magnet effect with a group of adults who are native speakers of English using both native and non-native vowels Individual prototypes were identified and participants compared variants of their prototypes in three stimulus conditions, prototype paired with variant, non-prototype paired with variant, and non-native vowel paired with variant Participants judged whether two vowels presented as a pair were the same or different To provide the most support for the perceptual magnet effect, the obtained results would have to reveal discrimination of pairs best in the non-prototype and non-native conditions The researchers found that discrimination was significantly better in the non-prototype condition than the prototype condition However, results did not indicate a significant difference between the prototype condition and the non-native vowel condition In all conditions, as the stimuli moved further away from the referent in the vowel space, discrimination improved An interaction between condition and distance would provide the most support for the perceptual magnet effect However, an interaction was not found to occur Therefore, the authors note that these findings provide only weak support for the theory

Sussman and Lauckner-Morano (1995) tested the perceptual magnet effect and found that the effect may be present in some vowel categories However, they note that the obtained results may not be completely attributable to the effect The authors suggest that the results may be explained by "increased auditory resolution" as tokens move away from the prototype An investigation of the perceptual magnet effect using mismatched negativity auditory evoked potential was completed by Sharma and Dorman (1998) The investigators conducted two experiments, one behavioral and one electrophysiological For the behavioral experiment, the researchers used parameters for two stimuli as reported by Kuhl (1991) These stimuli were Kuhl's prototype and non-prototype Eleven other stimuli were synthesized on a continuum between Kuhl's prototype and non-prototype Participants were given the task of assigning "goodness ratings" to the stimuli The rating scale followed that of Kuhl "1" being the poorest exemplar of the target and "7" being the best exemplar Results indicate that tokens near the end of the continuum were more appropriately discriminated than tokens near the center Sharma and Dorman note that if results of discrimination of tokens near Kuhl's prototype and non-prototype are compared, then the perceptual magnet effect is supported However, when discrimination rates between the true prototype and non-prototype, based on goodness ratings, are investigated, the magnet effect is not observed In the electrophysiologic experiment, the same synthetic stimuli used in the first experiment were used to elicit an auditory evoked potential The stimuli were presented pairing a variant with a reference (i e, 1-3, 3-5, 5-7) Stimulus number five was the prototype used in the initial study Electrodes were placed on the midline, on each side of the head and on the mastoid bones The response that was longest in duration and larger in area was achieved using the 1-3 pair A main effect of stimulus condition was noted Thus, the authors suggest "the vowel /i/ category exhibits an internal structure based on acoustic properties" (p 514) Therefore, the perceptual magnet effect would not be expected to affect discrimination

Although some research provides opposition for the perceptual magnet effect (Lively & Pisoni, 1997, Sharma & Dorman, 1998) the concept should not be completely discounted The perceptual magnet effect is related to categorical boundaries If vowels are identified based on perceptual categories, then greater variance will be noted between tokens located at boundaries than in centers of perceptual vowel space Thus, perception based on categorical boundaries offers some support for the perceptual magnet effect

Categorical Boundaries

Categorical perception of vowels assumes that when a vowel is perceived, it is compared to a referent within one's memory These referents may be in the center of the specific vowel space, typically referred to as the "best exemplar," or on the boundary between two vowel spaces The focus of categorical boundaries shifts perception based on the best exemplar to perception based on the tokens at the edge of the vowel space Perceptual anchors, representing extremes of stimulus ranges, are retained in memory (Macmillan, Goldberg, & Braida, 1988) Incoming acoustic stimuli are compared to the anchors The closer an acoustic signal is to the anchor, the more accurately the stimulus is perceived

Categorical perception in adults Categorical boundaries have been studied in adults using synthetic speech stimuli Nábělek et al (1993) investigated the perceived boundary between the English vowels /ɪ/ and /ɛ/ and the effects of the direction of formant trajectories Fifteen tokens were synthesized using data from Peterson and Barney (1952) In condition one of the first of three experiments reported, all formants of the stimuli were steady-state. The tokens varied in the frequency of the first formant Participants were "young-to-middle age" college students, either normal hearing or hearing-impaired Three conditions of the continuum were evaluated, a continuum degraded by reverberation, degraded by noise, and in quiet Boundary locations for both subject groups were similar across all listening conditions In the normal hearing group, the steepest identification slope was seen in stimuli presented in a quiet condition, followed by reverberation and noise, respectively In noise, the hearing impaired group exhibited shallower slopes than those of the normal hearing group In conditions of quiet and reverberation, slopes for the hearing impaired group were similar

The categorical structure of synthetically produced [ɪ] has been studied in adults (Sussman & Gekas, 1997) An original prototype was established along with 32 variants. Participants rated the prototype and variants as "best exemplars" of [ɪ] Using the responses of the participants, a second set of stimuli was generated around an [ɪ] prototype that elicited the highest identification rate among participants A third set of stimuli was synthesized based on the identification rates of stimuli of the first two sets and parameters described by Peterson and Barney (1952) For the first two stimuli sets, participants transcribed the perceived sound For the remaining stimuli set, participants labeled each token as either [ɪ] or not [ɪ] Patterns of responses were unique The authors report that the perceptual space for [ɪ] is small and that categories are specific to individual listeners

Sussman and Gekas' (1997) second experiment attempted to define the perceptual category space for [ɪ] Stimuli were created around the best exemplar identified in experiment one A total of 104 variant tokens were synthesized Participants labeled each presentation as either [ɪ] or not [ɪ] Results obtained from responses revealed four patterns of categorical labeling These include, circular, left-extending, downward, and upward Taken together, average responses of the participants revealed a graded pattern of response tokens near the center received more labels than those on vectors away from the center However, the authors note that this finding was not seen in any individual's response pattern

In Sussman and Gekas' (1997) third experiment, the researchers investigated the participants' choices of tokens that represent the best exemplar Each participant heard only stimuli that he labeled as [ɪ] in 50% or more of the trials in experiment two The task was a forced choice task in which the participants chose between "best [ɪ]" and "other " Results showed that most participants labeled tokens near the center of the category as best exemplar However, there was variability among listeners Two types of categorizers emerged Fifty-four percent of the participants identified best exemplar choices around the center of the category Forty-six percent of the participants identified exemplars near the edge of the category While some individuals use anchors at the categorical boundaries to facilitate vowel perception, others use centers of perceptual vowel spaces to aid perception

Categorical perception in infants and children Categorical perception in infants has been investigated (e g , Grieser & Kuhl, 1989, Marean, Werner, & Kuhl, 1992) In Grieser and Kuhl's study, [i] and [ɛ] were synthesized based on previously reported data (Peterson & Barney, 1952). Vowel centers were established and 32 variants were synthesized around the center Stimuli were presented to 6-month-old infants Using a head turn technique to indicate responses, the researchers measured the discrimination ability of the infants with a change and no change task and the use of categorization by the infants The latter was measured by a head turn response to a novel stimulus The findings indicate that 6-month-old infants categorize variants of vowels even when they are not the best exemplar of the vowel

To extend the findings of the previous study, Marean et al (1992) investigated vowel categorization in three groups of infants They used a head turn procedure to evaluate responses of 2-, 3-, and 6-month-old infants Stimuli were four synthesized tokens of /ɑ/ and

/i/ for a total of eight stimuli Two of each vowel represented male productions and two female productions Two of each vowel token had a rising fundamental frequency and two of each token had a falling fundamental frequency The 2-month-old infants displayed an appropriate response on 70% of stimuli with both voice and vowel change The percentage increased to 80% for voice change only and for vowel change only Thus, infants as young as 2-months-old appear to categorize vowels which are spectrally dissimilar and when produced by different people In the following section, the focus turns to perception research investigating the center of the perceptual spaces

Categorization as a developmental process. Ohde et al (1996) investigated the development of vowel perception in children using CV syllables constructed from voiced stop plosive consonants These consonants differed only in place of articulation Subjects were 5-, 6-, 7-, 9-, and 11-year-old children and adults The stimuli were synthesized syllables of [b], [d], and [g] combined with [i], [ɑ], and [u] The duration of the stimuli was set at 10, 30 and 46 ms A high rate of identification was achieved (i e , 80%) across stimulus types and listener groups The younger children had more difficulty identifying vowels in [g] and [b] contexts than those in [d] contexts The 11-year-old children's identification of vowels in [g] and [b] contexts mirrored that of adults Vowels produced in [d] context resulted in similar identification rates among all participants including adults Children had more difficulty identifying vowels with shorter durations than longer ones. However, duration did not affect adults' identification rates

To extend the previous study, Ohde and Haley (1997) attempted to replicate the findings with adults, 4-year-old children and 3-year-old children The researchers chose two of the consonants from their previous research (i e , [d] and [g]) and paired them with three vowels (i e , [i], [u], and [ɑ]) to produce CV contexts Stimuli varied in duration of either 10, 30, or 46 ms, and moving or straight formant transitions Identification rates were above 80% for 4-year-olds and adults across all stimuli Both groups of children exhibited higher identification rates when identifying the vowels with moving formant transitions than straight transitions However, adults did not differ in identification rates of syllables with or without formant transitions Thus, children may rely on formant transitions to facilitate vowel identification The researchers then investigated the ability of children to identify vowels from short duration onsets The findings indicate that the longer the duration, the higher the correct identification for 3-year-old children Four-year-old children had higher identification rates for the two longer duration stimuli than for the shorter duration stimuli However, a difference was not seen in the two longer duration stimuli Adults tended to identify vowels based on short duration onset Thus, these results suggest the process of vowel perception changes across ages and becomes more efficient in adults

Support for changes in vowel perception as age advances is also provided by Walley and Flege (1999) They created two continua with two native vowels (i e , /i/ and /ɪ/) on one and a native vowel to a non-native vowel (i.e , /ɪ/ and /Y/) on the other Each vowel token was embedded in a CVC context (i e , /hVb/) which yielded non-words Eight tokens were synthesized on each continuum Listeners were 5- and 9-year-old children and adults Stimuli were presented individually Participants were instructed to press one button when they heard /hib/ and another button when they heard the other word (hYb) Identification functions were analyzed for each group The boundary between the two endpoints and the slope at the boundary were analyzed for each continuum Slope comparisons of the native-native continuum revealed that as the age of the participant increased so did the slope A statistically significant difference was found in slopes of younger children and adults Comparisons of the native to non-native continuum revealed differences between the younger children and both of the remaining groups Slopes exhibited by older child group paralleled those of adults Boundaries for the three age groups were not significantly different on either continuum

Categorization of vowels in children with language impairments. If individuals use more efficient factors to facilitate vowel perception as age progresses, do language-impaired children's perceptions mirror that of their typically developing counterparts? Stark and Heinz (1996) investigated vowel perception in children with and without language impairment Participants ranged in age from 6- to 10-years-old Two sets of stimuli were synthesized /ɑ/ - /i/ and /ɛ/ - /æ/ The former of these stimuli were used to validate an understanding of the task because these two vowels are spectrally dissimilar and should be discriminated with little difficulty The latter pair of stimuli were chosen because they are both low front vowels and have acoustic features that are similar Duration for stimuli was manipulated such that six tokens were synthesized varying in duration from 40 to 240 ms in six equal steps Tasks included identification, discrimination, and temporal ordering Both groups of children had more success with identification task with /i/ - /ɑ/ stimuli than with /ɛ/ - /æ/ However, language-impaired children were less accurate in identification and required more prompts and repetitions to identify the first set of stimuli

Elliott and Hammer (1988) also investigated differences in perception between typically developing children (R) and children with language-learning problems (LP) The longitudinal study documented participants' progress for 3 years Participants were 6- and 7-years-old at the onset of the investigation and 9 to 10 at the completion of the study Each year, measures of the participants' receptive vocabulary and language were obtained Additionally, articulatory abilities were assessed The experimental task used CV tokens on a continuum varying in voice onset time from 0 - 35 ms A second continuum contained tokens which varied in place of articulation of the initial consonant (i e , [ba], [da], and [ga]) These tokens were differentiated by the starting frequencies of the second and third formants and the onset bursts Measures of the experimental tasks were compared to results of language, vocabulary, and articulation tests A negative correlation was found between poor auditory discrimination and measures of receptive vocabulary and language Both groups improved their performance on the experimental task and on measures of linguistic development However, the scores of the LP group did not exhibit gains on the scores of the R group Thus, the LP group did not "catch up" to their typically developing peers.

If language-impaired children are less accurate in identification and auditory discrimination tasks than typically developing children, then would it be possible to predict language impairment based on children's inability to identify and discriminate vowels? Elliott, Hammer, and Scholl (1989) investigated the predictability of a fine grained auditory discrimination task on language-learning problems. The researchers conducted a study of 6- to 11-year-old children (n = 294) The participants were divided into two groups, younger children (6- and 7-year-old children) and older children (8 to 11 years) The ethnic and socio-economic status of the participants mirrored that of the United States Two continua of stimuli were synthesized varying in voice onset time (i e , 0-35 ms) and place of articulation ([ba-da-ga]) To achieve varying place of articulation, the researchers varied the frequencies of the second and third formants Participants completed an auditory discrimination task to determine a just noticeable difference (JND) of acoustic variations that could be discriminated Participants were also given tests which evaluated their receptive and expressive language skills Correlation was found between auditory discriminative ability and language ability, especially in the younger children When the investigators added tests of digit coding, block design, and coding, a higher correlation was noted When incorrect predictions were made based on auditory discrimination, more children were classified as typically developing rather than disordered If the link between auditory discriminative ability and language ability can be established, then, it may be possible to predict a language impairment based on a child's auditory discriminative ability. If this ability is influenced by the child's development of categorical perception, then a delay in this development may prove to be predictive of a language impairment

Statement of Purpose

It is well documented that adults show clear boundaries and steep slopes when their categorical perception of vowels is tested (e g , Nábělek et al , 1993) Using one lax and one tense vowel (i e , [ɪ] and [i], respectively) researchers have shown a similar effect in children with vowels embedded in CVC nonwords (e g , Walley & Flege, 1999) . However, investigators have yet to test children's categorical perception of isolated vowels using a continuum of variants between two lax vowels (e g , [ɪ] and [ɛ]) Thus, the present investigation attempts to identify the boundary between synthetic [ɪ] and [ɛ] as defined by adults, older children (10-year-olds), and younger children (5- and 6-year-old children) Specifically, do these three groups of participants identify the boundary between the two synthetic vowels on the same variant? Using logit transformation, the functions at the boundary will be smoothed before determining the slope at the boundary Do groups of participants exhibit similar slopes at the boundaries? If not, does the variance exhibited among the groups indicate that the use of categorical boundaries to facilitate vowel perception is developmental? Do responses parallel those previously identified for adults (Nábělek et al , 1993) and children (Walley & Flege, 1999)? Additionally, a steeper slope at the boundary than on points near the vowel centers would support goodness of fit theory and a more shallow slope across all tokens would fail to provide support Using data gathered to identify slopes, does the steepness of these slopes support goodness of fit theory across the groups?

CHAPTER II

Method

Subjects

Three groups of participants, differentiated by age, participated in this study Group one consisted of 10 adults and groups two and three each consisted of 10 children between the ages of 10 0 and 10 11 (years months) and 5 8 and 6 8, respectively All participants were monolingual and English was the only language spoken in their home Additionally, all participants had pure tone thresholds at or below 20 dB HL across the speech frequencies (500, 1000, 2000, and 4000 Hz) Parents of child participants reported any history of ear infections Four children had PE tubes placed at or before the age of two However, parents stated that these children have had few, if any, ear infections since that time One child had a second set of tubes in place Three of the remaining children had experienced some ear infections but most were prior to the age of two One child had a history of swimmer's ear

With the exception of one participant, all of the 10-year-old participants were either enrolled in or just completing fourth grade The remaining child in the older child group was just completing fifth grade All of the participants in the younger child group were either enrolled in or just completing kindergarten giving them little exposure to formal reading instruction

Child participants had no previous history of speech or language disorders as reported by their parents The <u>Templin-Darley Tests of Articulation (T-D)</u> (Templin & Darley, 1969) Screening test, 11-item Vowel Grouping subtest, and 6-item Diphthong Grouping subtest were administered to determine age appropriate articulatory abilities. Receptive and expressive language abilities were assessed using the Clinical Evaluation of Language Fundamentals-3rd ed (CELF-3) (Semel, Wiig, & Secord, 1995) or the Clinical Evaluation of Language Fundamentals-Preschool (CELF-P) (Wiig, Secord, & Semel, 1992). The Deletion subtest of the Phonological Awareness Test (PAT) (Robertson & Salter, 1997) was used to assess the child's ability to segment syllables and phonemes For inclusion in the present study, all child participants scored above minus one standard deviation of the mean score of same age peers on all assessments Additionally, all children were placed in regular classrooms, had received no special services for developmental disabilities (speech-language, learning disabilities, reading), and had passed each grade attempted on initial attempt as determined by parental report One participant in the older child group was receiving enrichment services for gifted students

Adult participants were graduate college students taking courses in the Department of Audiology and Speech Pathology Adult participants had normal speech, language, and cognitive skills as evidenced by their status as university students and information provided via a questionnaire

Potential adult participants were solicited through announcements made prior to the beginning of classes held within the Department of Audiology and Speech Pathology These announcements included a brief description of the present investigation Interested students were asked to sign their name and provide a means of communication for the researchers to contact them Upon receipt of the list of names, either Ms Susan Pursell or Dr Lori Swanson contacted interested students and scheduled appointments for single sessions which did not conflict with participants' class or clinic schedules A background questionnaire (see Appendix A) and fact sheet containing detailed information concerning the study (see Appendix B) were given to the students prior to the session and written consent (see Appendix C) was obtained prior to any data collection Student participants received extra credit for course work from their class instructors

Potential child participants were solicited through personal contacts and contacts with various organizations (private schools, private daycares, and local churches) A fact sheet (see Appendix B) describing the study and a consent form (see Appendix D) were given to parents upon approval of the administration of the cooperating agency A contact person from the participating agency collected the consent forms and returned them to the researchers Upon receipt of consent forms, the researchers provided a background questionnaire (see Appendix E) Either Ms Susan Pursell or Dr Lori Swanson contacted the parent to schedule appointments for two sessions on separate days

Stimuli

The vowels [ɪ] and [ɛ] were selected to serve as stimuli for this perception task. /ɪ/ and /ɛ/ were chosen because they are both lax vowels and adjacent to one another in perceptual vowel space as defined by Peterson and Barney (1952) and Hillenbrand et al (1995) Additionally, /ɪ/ and /ɛ/ have been the focus of previous investigations (e g , Nábělek et al., 1993) Fourteen vowel variants or tokens representing steps on a continuum from /ɪ/ to /ɛ/ were generated by Klatt's cascade-parallel speech synthesizer Tokens were differentiated by the frequency of the first formant (F1) of the vowel A similar continuum varying in frequency of F1 has been reported (Nábělek et al , 1993) The frequency of F1 changed in equal steps across the continuum, from 400 Hz to 510 Hz, and the bandwidth remained static at 50 Hz The frequency of F1 of the first token was 400 Hz and the bandwidth (BW) was 50 Hz The frequency increased by 10 Hz at each step until reaching 530 Hz on the last token (see Table 2-1) Bandwidths and the remaining formants were constant for all tokens For F2, the frequency was 2000 Hz, with a BW of 100 Hz The frequency of F3 was constant at 2500 Hz and BW3 = 190, F4 at 3300 Hz and BW4 = 250, and F5 at 3850 Hz and BW5 = 300. This continuum was modeled after values previously reported (Nábělek et al , 1993) However, the range of values for F1 are more narrow than those previously reported The present author listened to presentations of [ɪ] based on previously published parameters (e g , Nábělek et al , 1993, Sussman & Gekas, 1997) and values between those previously stated Perceptually, an F1 of 400 Hz yielded the best [ɪ] to the principal investigator During pilot testing, the stimuli were tested and their quality was accepted by two speech-language pathologists familiar with synthesized speech The values of the frequencies of the first and second formants were consistent with perceptual vowel spaces identified by Peterson and Barney (1952) and Hillenbrand et al (1995) All tokens had a duration of 200 ms

To ensure quality of stimuli, a pilot study was conducted in which ten of each endpoint were presented to seven untrained adult listeners The participants were graduate students in the Department of Audiology and Speech Pathology and had little previous experience listening to synthetic speech The students heard a vowel in isolation and then

Table 2-1 Formant frequencies and bandwidths for each stimulus

		Token Number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
F1	*f*	400	410	420	430	440	450	460	470	480	490	500	510	520	530
	BW	50 Hz													
F2	*f*	2000 Hz													
	BW	100 Hz													
F3	*f*	2500 Hz													
	BW	190 Hz													
F4	*f*	3300 Hz													
	BW	250 Hz													
F5	*f*	3850 Hz													
	BW	300 Hz													

were asked to write the American Phonetic Alphabet symbol that corresponded to the vowel they perceived All of the presentations of token number one (i e , [ɪ]) were correctly identified by four of the seven students All of the presentations of token number fourteen (i e , [ɛ]) were correctly identified by five of the students Two trained listeners were then asked to identify the endpoint tokens These judges were speech-language pathologists who had experience in listening to synthetic speech They correctly identified the two endpoint stimuli in 100% of trials Following identification of the endpoint stimuli, the two trained listeners were asked to judge the remaining stimuli for their quality Both trained listeners accepted the quality of the stimuli

In the next step of the pilot study, the stimuli were presented to six untrained child listeners (three 4-year-old children and three 7-year-old children) to determine their ability to complete the task The children were told that they would hear a sound that was either [ɪ] or [ɛ] They were instructed to point to either a picture representing [ɪ] (an Indian) or [ɛ] (an elephant) The first stimuli presented were the vowels produced in isolation by the researcher in natural speech This was completed to help facilitate the association of the sounds with the pictures Following the natural speech presentations, 20 presentations of two synthetic vowels were presented These vowels were the endpoint tokens of the continuum The younger group of children was unable to associate the sounds with the pictures However, the 7-year-old children completed the task identifying the tokens with 100% accuracy Based on these findings, it was concluded that preschool children would exhibit difficulty completing the task Further, children in kindergarten may be more suited for successful task completion

During the experimental sessions, stimuli were randomly generated by and presented using a Compaq computer During test trials, stimuli were presented monaurally to the right ear of participants via Sony headphones (model MDR-V600) The right ear was selected due to reported slight right ear advantage to linguistic stimuli and to avoid effects of binaural hearing Each token was randomly presented 10 times yielding a total of 140 presentation trials for each participant

Procedure

First sessions for child participants were held in the Child Language Laboratory (Room 432 in South Stadium Hall at the University of Tennessee) This lab is equipped with an audiological booth which is suitable for hearing evaluations and speech-language assessments Child size chairs and a child size table were available for use Sessions were conducted by Ms Susan Pursell The second session for child participants and all sessions for adult participants were held in the Speech Perception Laboratory (Room 557 in South Stadium Hall at the University of Tennessee) This lab is also equipped with an audiological booth which is suitable for speech perception research Prior to any data collection, each participant and parents of child participants were informed about the project He/she was given an age appropriate explanation of the project by Ms Pursell Written consent was obtained from adult participants and from parents of child participants (see Appendices C and D) Additionally, verbal assent was obtained from child participants (see Appendix F) Verbal assent was audio taped To limit distractions to participants, those accompanying subjects to the session were asked to sit outside the audiological booth and observe via a window in the audiological booth

Child Participants' First Session: Criteria Measures

The focus of the first session was to obtain data for inclusion in the study Prior to the first session, each participant's parent was contacted by one of the researchers to gain background information During the first session, a brief parent interview was conducted to confirm that English is the only language spoken in the home and that there had been no history of any speech and/or language disorders After the interview, the participants' hearing was evaluated using bilateral pure-tone threshold testing across speech frequencies (500, 1000, 2000, and 4000 Hz) using a Maico audiometer (model MA40) A sticker was given after the hearing evaluation was completed The CELF-3 or CELF-P (dependent upon participant's age) was administered to evaluate participant's expressive and receptive language abilities Stickers were given to the participant throughout the test for his/her cooperation A five minute break followed the administration of the language evaluation During this break, the participant was given the opportunity to get a drink of water if desired The screening test and the Vowel and Diphthong groupings of the T-D were given to evaluate the participant's articulatory abilities Finally, the Deletion subtest of the PAT was administered Standard scores for individuals are reported for the CELF-3 or CELF-P for all children, and the Deletion subtest of the PAT for the younger children (see Appendix G) Standard scores are not given for the older group of children on the PAT This test does not have norms available above the age of 9 years and 11 months Instead, to aid in data analysis, percentage correct scores are given for both groups of children

At the end of the first session, participants chose a prize for their participation Prizes included various items purchased for less than $1 00 (i e , sunglasses, bracelets, toy cars, markers, pens and pencils with pencil toppers, etc) If at any point during the first session a participant failed to meet the inclusionary criteria, he/she was permitted to continue for the entire session Following the presentation of prizes and scoring of the assessments, the researcher explained to the parent that the present study is looking for specific children and his/her child did not meet the strict inclusionary criteria One child in the younger age group and three children in the older age group did not meet the inclusionary criteria Upon successful completion of criterion measures, children were scheduled to participate in session two

Child Participants' Second Session Experimental Data

The goal of the second session was to collect experimental data Prior to data collection, training was provided to participants to facilitate the association of pictures with the corresponding vowels /ɪ/ was represented by a picture of an "insect" (see Appendix H) /ɛ/ was represented by a picture of an "elephant" (see Appendix I) Participants were instructed (see Appendix J) to touch the picture that corresponded to the sound they heard Additionally, they were instructed to say the sound as they pointed to the picture Since the parameters of the stimuli most closely resembled those reported for a male speaking voice (Peterson & Barney, 1952), the first training stimuli were /ɪ/ and /ɛ/ produced by a male voice in natural speech Twenty presentations of two stimuli (one [ɪ] and one [ɛ]) were generated by Kay Elemetrics Corporation's Computerized Speech Lab (model 4300B) and recorded on type II audio tapes to be played from a Marantz portable cassette recorder (model PMD430) These stimuli were presented to children via Sony headphones (model MDR-V600) Children were required to correctly identify 90% of stimuli before proceeding Investigators provided positive verbal feedback for appropriate responses (i e , great, that's fine, nice work) Errors were corrected immediately If a participant did not meet the mastery level, then the instructions were repeated, followed by a demonstration During the demonstration, the investigator listened with the child to [ɪ] produced in natural speech Upon presentation of the stimulus, the researcher pointed to the appropriate picture and asked the child to do the same. Then the investigator and child listened to [ɛ] produced in natural speech After presentation of the stimulus, the investigator pointed to the appropriate picture and asked the child to do the same This procedure was repeated twice Then the researcher listened to a stimulus with the child and asked the child to point to the appropriate picture independently All but one of the child participants reached mastery of natural speech training on their first attempt The remaining child reached mastery on her second attempt If a participant did not meet mastery level after three attempts of training, he or she would have been removed from the study Positive verbal feedback was given to participants for following directions

Following the natural speech presentations, the participants practiced the task with synthetic tokens to familiarize them with the experimental stimuli (synthetic speech) These tokens were taken from the extreme ends of the continuum After being introduced individually (five repetitions of each), 10 presentations of stimulus number 1 (i e , [ɪ]) and 10 presentations of stimulus number 14 (i.e , [ɛ]) were randomly generated and presented via a Compaq computer Mastery level for the synthetic token portion of the training session was 80% If a participant failed to reach 80% on the first attempt, instructions were repeated and a demonstration was given The demonstration followed the format of the one previously described If a participant failed to meet mastery level after three attempts to train, he/she was removed from the study Although all of the children in the older age group completed the training successfully, one child in the younger age group did not and had to be removed from the study Positive verbal feedback was given to all children for cooperation

Following mastery of traming stimuli, experimental data collection began. Stimuli were presented monaurally to the participants via Sony headphones (model MDR-V600) and simultaneously to the researcher via a separate pair of headphones Stimuli were randomly generated and presented via a Compaq computer Each token was generated 10 tmes for a total of 140 presentation trials Two pictures representing "insect" and "elephant" were placed in front of the participants Upon presentation of a stimulus, subjects touched/pointed to the picture which corresponded to the vowel he/she perceived [ɪ] or [ɛ] while simultaneously saying the sound Participants were told that some stimuli would be difficult to discrimmnate and that they should select the picture that best represented the sound they heard Additionally, they were instructed to respond to all stimuli as quickly as possible Responses were recorded by the researcher on a response form and on a computer by clicking on the appropriate half of the monitor screen Positive verbal feedback was given randomly once during each set of 14 presentations After presentation of 70 stimuli, or more often if needed to ensure cooperation, children were given an opportunity to select a sticker for cooperation A five minute break was given after presentation of 70 stimuli to allow participants to stretch and obtain a drink of water, if desired During this break, the researchers walked down a hallway with participants Upon completion of data collection, participants were permitted to select a prize from the pool of prizes previously described Parents and participants were thanked for the participation

Adult Session Criteria Measures and Experimental Data

Adults were seen for a single, one-hour session A brief interview was conducted to verify information obtained from the background questionnaire Bilateral pure-tone threshold testing across speech frequencies (500, 1000, 2000, and 4000 Hz) using a Maico audiometer (model MA40) followed the interview Only one participant did not pass the hearing evaluation Although this participant continued for the entire session, data collected from her were not used in any analysis Prior to data collection, training was provided to participants to familiarize them with synthetic speech Participants were informed that stimuli were synthesized vowels /ɪ/ and /ɛ/. A training tape of 20 random presentations of the endpoint stimuli was presented Participants were instructed to mark either /ɪ/ or /ɛ/ on a training response form for each stimulus Participants were required to correctly label 90% of stimuli before proceeding All adult participants successfully completed the training trials Corrective feedback was given following any incorrect responses

Following mastery of training stimuli, experimental data collection began Participants listened to stimuli and choose between two vowels After instructions were given (see Appendix K) to participants, stimuli were presented monaurally to the right ear via Sony headphones (model MDR-V600) A total of 140 stimuli were randomly presented, 10 of each token. Participants were asked to use a mouse to guide a cursor on a computer screen and click on the appropriate half The left side of the screen was labeled /ɪ/ and the right half of the screen was labeled /ɛ/ Participants were told that some stimuli would be difficult to determine and participants were instructed to guess when a stimulus was difficult to discriminate After 70 presentations, subjects were given the option to take a five minute break The experimental session lasted for approximately 35 to 40 minutes and all adult participants opted not to take a break Following completion of data collection, participants were thanked for their cooperation

Scoring

Scoring the responses of children was a two-step process Immediately after the child responded, the principal investigator marked the response on a response form (see Appendix L) After hand-marking the response form, the investigator used a mouse to record the response on the computer

When children made a change in decision within seconds, the second choice was noted on the hand-scored form which resulted in some discrepancies between the hand-scored sheets and the computer print-outs However, changes were noted on the computer print-outs and only the responses scored on the hand-scored sheets were used to analyze data

Additionally, five of the data sets did not contain 140 responses (three contained 139 and two contained 138) On a one occasion, a participant responded that she didn't hear a stimulus The computer used to generate stimuli did not play a signal or failed to play it in its entirety on four occasions The examiner failed to see responses on two occasions All of these items were discarded

Intra- and Inter-Judge Reliabılıty

Two score sheets were available for use, the hand-scored form and the computer print-out of responses Only one discrepancy was noted between the two score forms On that occasion, the hand scored response was used ın data analysis

The principal investigator was careful to maintain a head position that was directed toward the computer screen which was visible through a window in the audiological booth Thıs was done to reduce any tester effects that may have influenced the child's response Therefore, since the ınvestigator's eye gaze was not directly on the pictures, inter-judge reliability is necessitated to validate results Inter-judge reliabılıty was established by Dr Lori Swanson She hand-scored test forms during experimental data collection for five of the children. For all but one of the children, inter-judge relıabılity was 100% For the remaining chıld, it was 99 3%

CHAPTER III

Results

Data collected were analyzed to determine two separate variables for each participant First, the categorical boundary was determined for each individual A percentage of [ɪ] responses for each token was calculated from the raw data (see Appendix M) for each participant The 50% response point defined the boundary Boundaries among groups were compared Second, using logit transformation, the individual functions at the boundary were smoothed before determining the slope Mean slopes for each group were calculated and compared

Categorical Boundary

Using logit transformation, the resulting line from the plotting of percentage of [ɪ] responses as a function of token number was smoothed (see Figures 1, 2, and 3 for individual graphs) The 50% response point defined the boundary for each participant.

An average boundary was calculated for each of the three groups of participants (see Table 3-1) Mean boundaries (with standard deviations in parentheses) for adults, older children, and younger children were 6 58 (0 65), 7 56 (0 98), and 6 93 (1 04), respectively Between group comparisons were examined to address development of categorical perception across age A one-way, between groups, ANOVA was used to evaluate the main effect of group on the variance of boundary selection (see Table 3-2) Findings revealed no statistically significant difference among groups, $\underline{F}$ (2, 29) = 3 026, $\underline{p}$ = 065

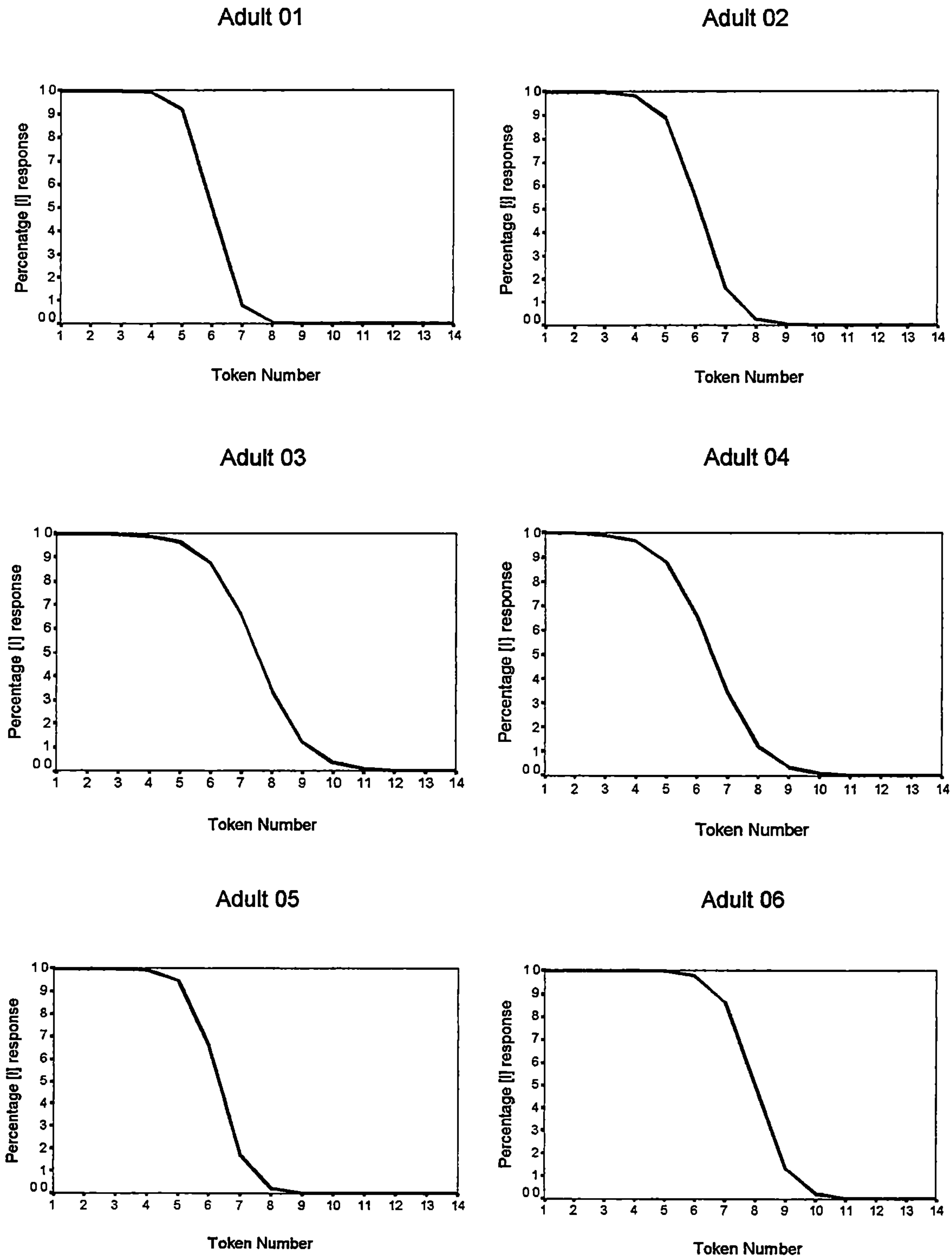

Figure 1 Percentage [ɪ] responses as a function of token number for adults (continued on next page)

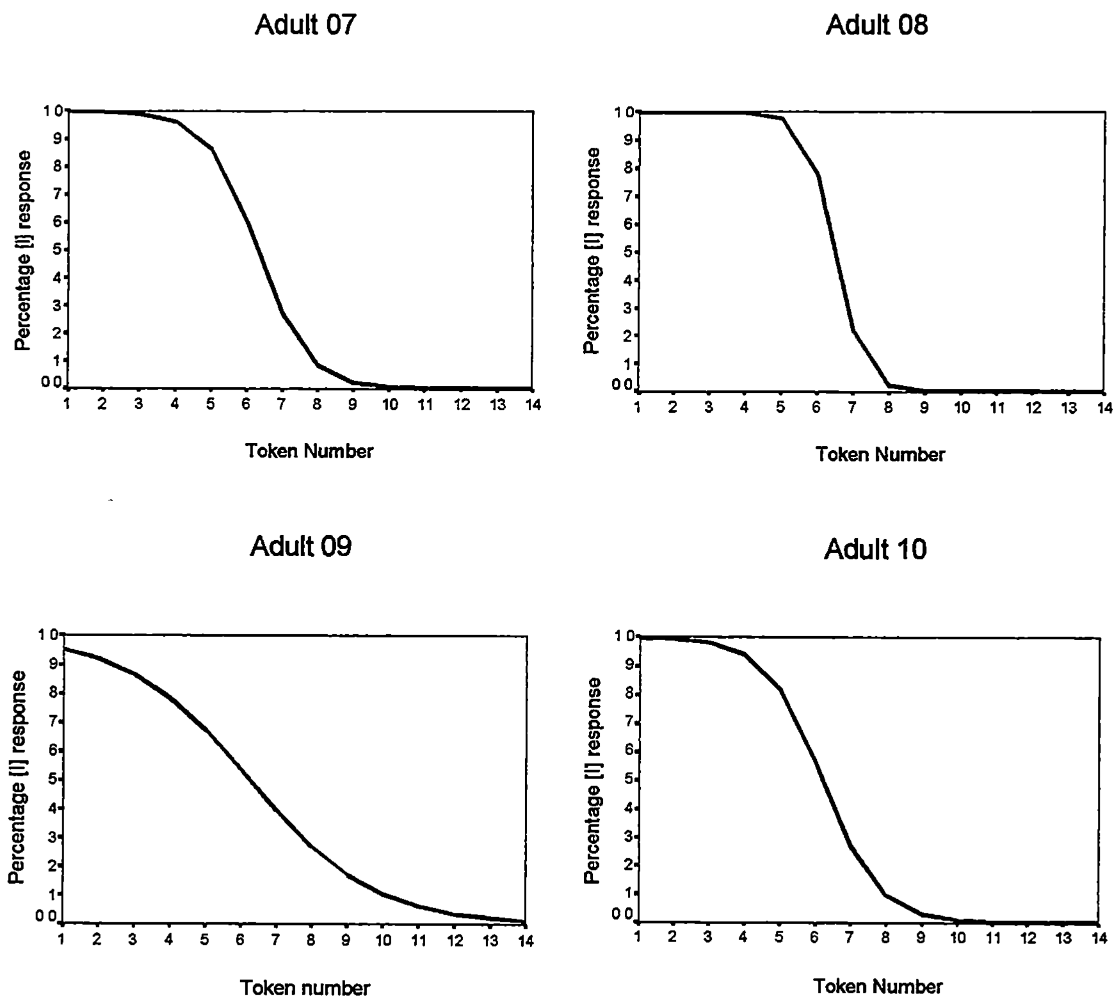

Figure 1 (continued)

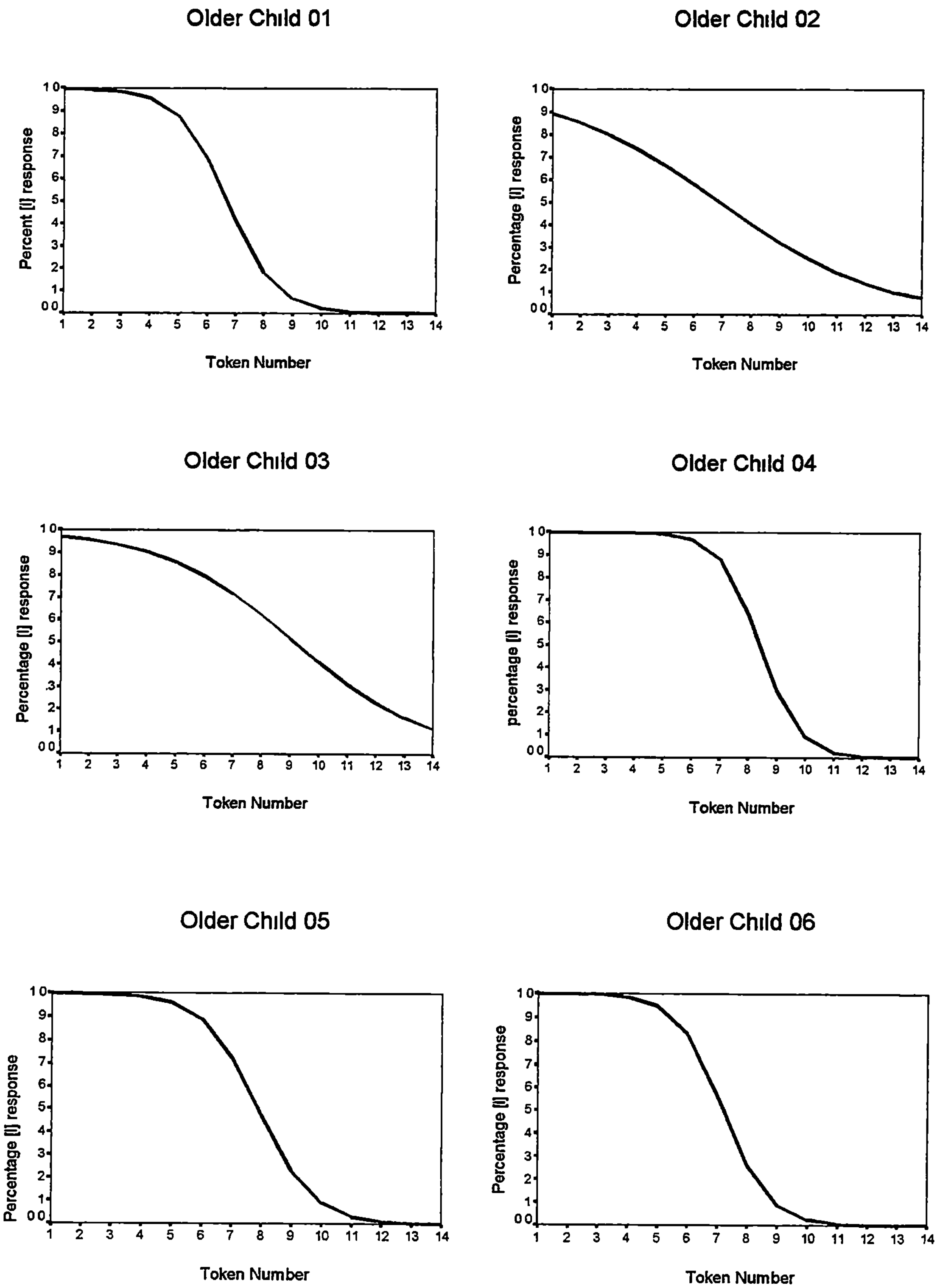

Figure 2 Percentage [ɪ] responses as a function of token number for older children (continued on next page)

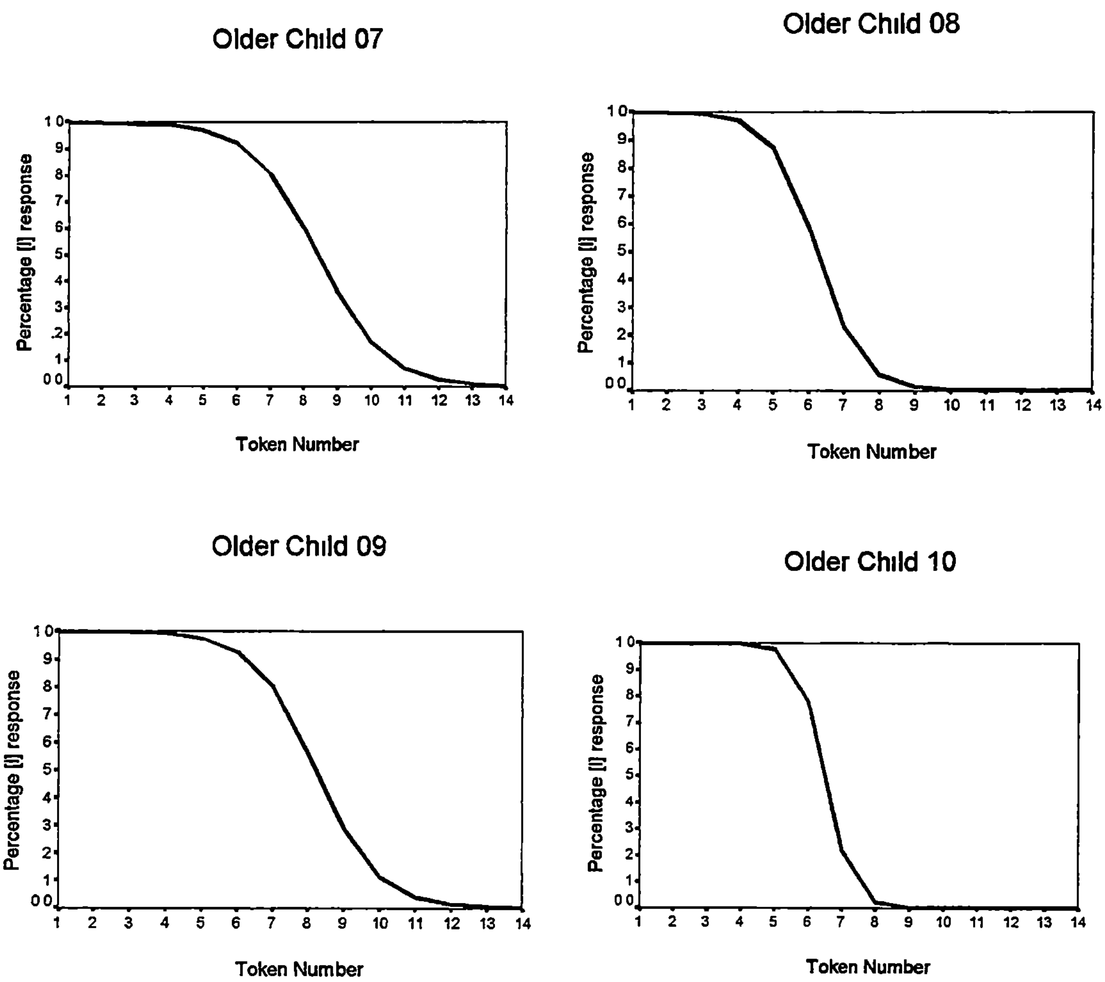

Figure 2 (continued)

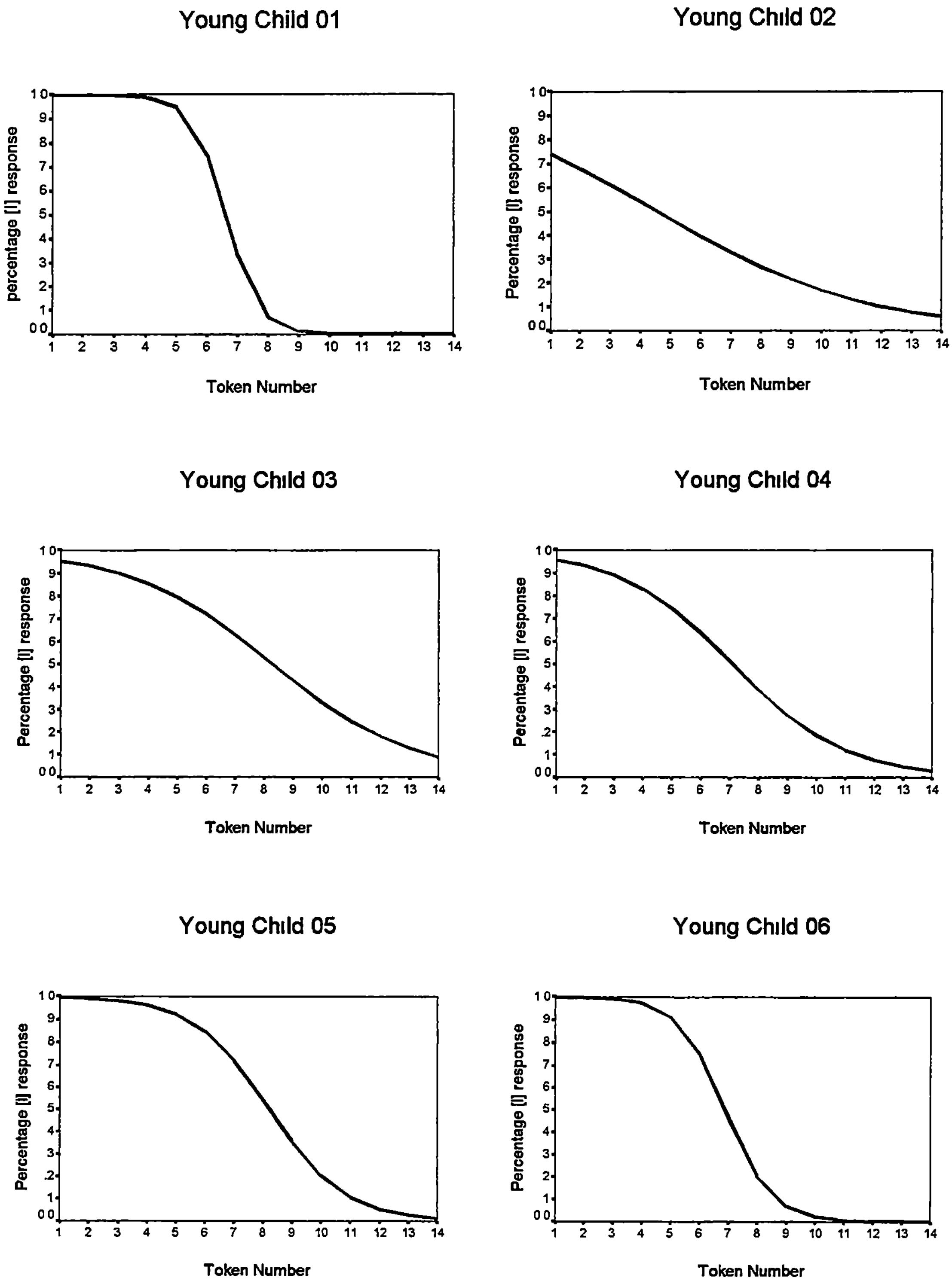

Figure 3 Percentage [ɪ] responses as a function of token number for younger children (continued on next page)

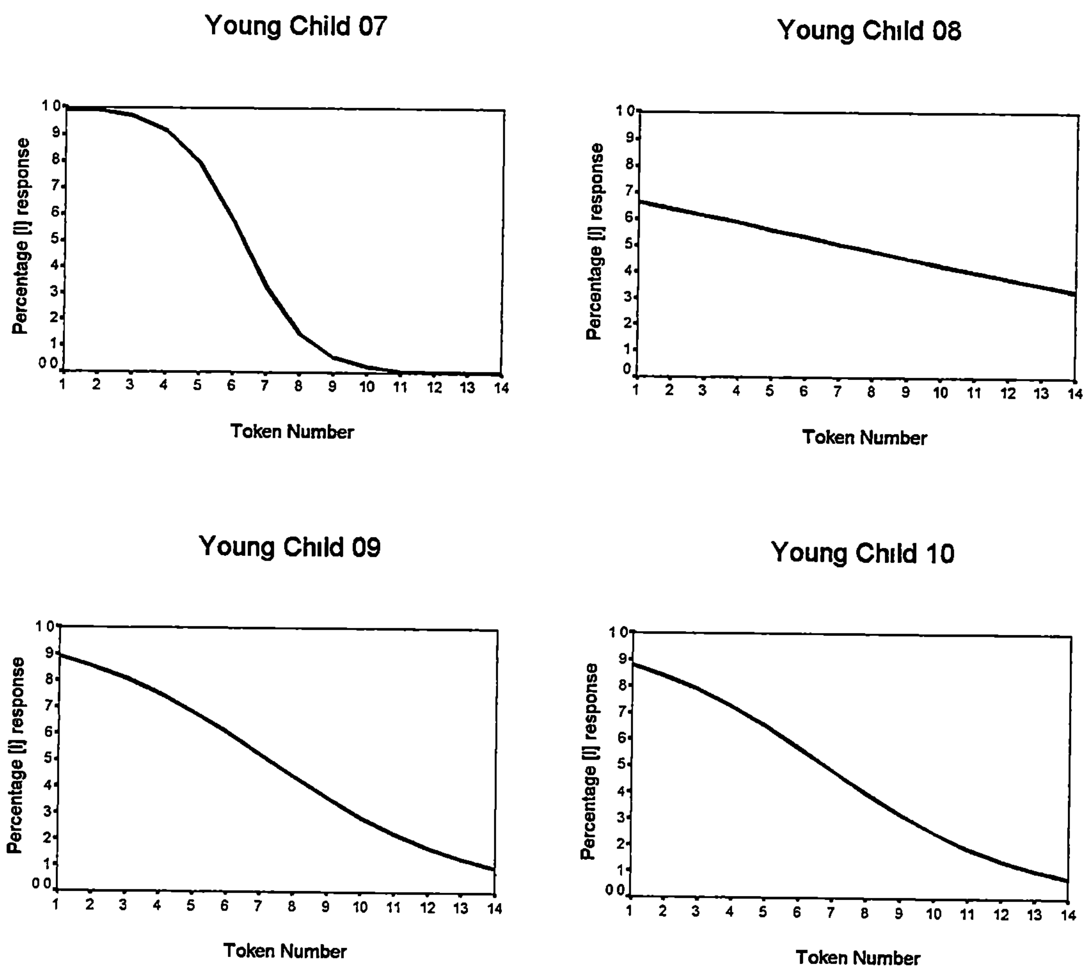

Figure 3 (continued)

Table 3-1 Individual and group means for boundary identification

Participant Number	Group 1 (adults)		Group 2 (older children)		Group 3 (younger children)	
	50% response	*SD*	50% response	*SD*	50% response	*SD*
1	5 999		6 699		6 601	
2	6 101		6 918		4 611	
3	7 500		9 159		8 291	
4	6 502		8 401		7 204	
5	6 299		7 897		8 228	
6	8 001		7 198		6 903	
7	6 298		8 415		6 202	
8	6 499		6 228		7 194	
9	6 255		8 210		7.256	
10	6 299		6 499		6.784	
Sample Means	6 575	0 64877	7 562	0 98404	6 927	1 04489

<u>Note</u> The 50% response defines the boundary location between the two vowels

Table 3-2 Analysis of variance for the main effect of group in boundary selection

Source	df (degrees of freedom)	SS (sum of squares)	MS (mean square)	F
Between groups	2 (k - 1)	5 005	2 503	3 026
Within groups	27 (N - k)	22.330	0 827	
Total	29 (N - 1)	27 335		

Note. No statistically significant difference noted among groups

Slope

To determine whether the present results support "goodness of fit" theory, the slope at the boundary was identified for each individual Using logit transformation, the individual functions at the boundary were smoothed before determining the slope A steep slope would support "goodness of fit" theory and a shallow slope would fail to support the theory

An average slope was calculated for each of the three groups (see Table 3-3) Mean slopes (with standard deviations in parentheses) for adults, older children, and younger children were 0 416 (1 53), 0 299 (0 15), and 0 178 (0 14), respectively Between group comparisons were examined to address development of categorical perception across age A one-way, between groups, ANOVA was used to evaluate the main effect of group on the variance of slope (see Table 3-4) A statistically significant difference was found among groups, $\underline{F}$ (2,29) = 6 528, $\underline{p}$ = .005 A *post hoc* Tukey test revealed a statistically significant

Table 3-3 Individual and group means for slope at the boundary

Participant Number	Group 1 (adults)		Group 2 (older children)		Group 3 (younger children)	
	slope	*SD*	slope	*SD*	slope	*SD*
1	0 605		0 288		0 452	
2	0 464		0 089		0 068	
3	0 327		0 107		0 101	
4	0 327		0 358		0.135	
5	0 551		0.273		0 191	
6	0 461		0.327		0 308	
7	0 350		0 250		0 326	
8	0 628		0 388		0 027	
9	0 142		0 285		0 084	
10	0 309		0 628		0 086	
Sample Means	0 416	0 15273	0 299	0 15084	0 177	0 13906

<u>Note</u> Slope at the boundary reflects the slope at the 50% response point

Table 3-4 Analysis of varıance for the main effect of group on slope

Source	df (degrees of freedom)	SS (sum of squares)	MS (mean square)	F
Between groups	2	0 285	0 142	6 528
Within groups	27	0 589	2 181E-02	
Total	29	0 873		

Note A statistically significant difference among groups was found ($\underline{p} <$ 05)

difference in slopes between younger children and adults ($\underline{p} <$ 05) No statıstically sıgnıficant difference was found between the older children and eıther of the two remaining groups

Addıtıonal Analysis

In considering the results of steepness of slopes in this study and the ınclusıonary information obtained during the first session, the author ran a multi-variate correlational analysis. The factors considered in the analysis included, receptive and expressive language scores from either the CELF-3 or the CELF-P, and the percentage of correct responses on the Deletion subtest of the PAT Percentage correct scores were used for analysis because the PAT does not have norms available for partıcipants in the older age group A correlation was found between the steepness of slope and percentage of correct responses on PAT. A Pearson Correlatıon of $\underline{r} =$ 482, $\underline{p} =$ 031 was found

Summary of Results

These results indicate that the efficiency of categorical perception improves as age progresses as evidenced by differences in variance of slope between younger children and adults Although a statistically significant difference in slope was not found between older children and either younger children or adults, a general trend in slope was noted (see Figure 4) Adults exhibited the steepest slope, followed by the older children with the younger children exhibiting the most shallow slope

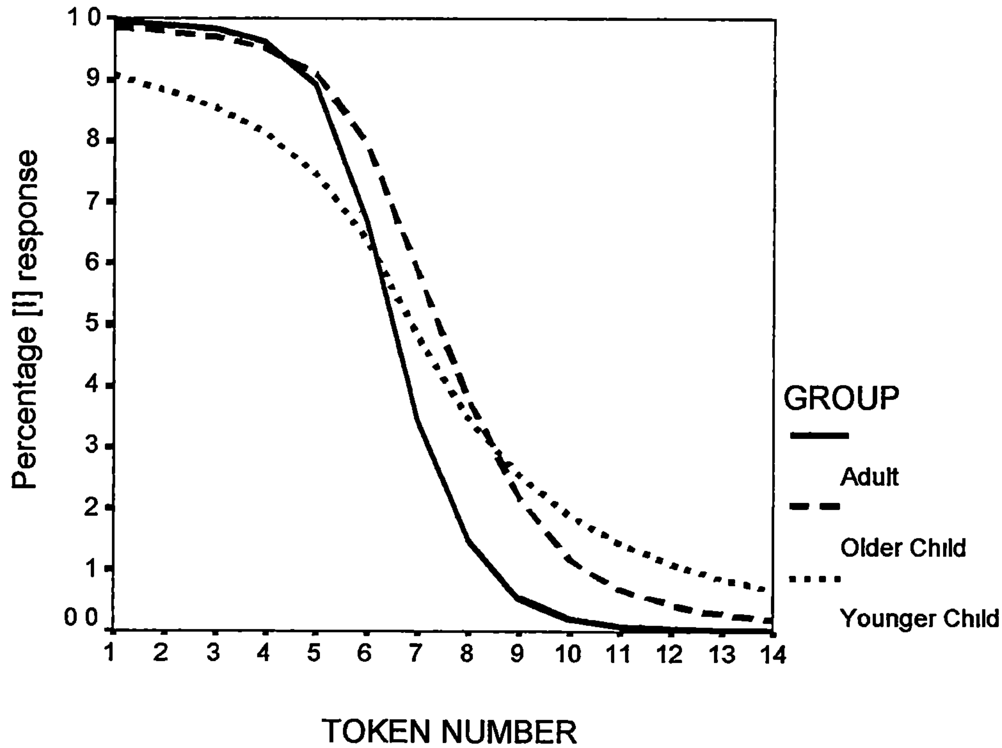

Figure 4 Percentage [ɪ] responses as a function of token number for groups

CHAPTER IV

Discussion

Purpose of Study

The purpose of this study was to investigate the categorical perception skills of school-age children and adults More specifically, the author was interested in comparing the location of the boundary between two vowels and slope at the boundary as defined by three groups of participants differentiated by age By identifying and comparing the boundaries and slopes at the boundaries, categorical perception as a developmental process could be tested Do children's categorical perception skills become more efficient as they advance in age? Additionally, do the present results parallel those previously reported (Nábělek et al., 1993, Walley & Flege, 1999)? A secondary purpose was to see if the present results support goodness of fit theory This is achieved by comparing slopes of response points near endpoints of the continuum (i e , 75% and 10% response points) with slopes at the boundary

Boundary

Boundaries between two vowels on opposite ends of a continuum have been investigated in adults and children (e g , Nábělek et al , 1993, Walley & Flege, 1999) Previous studies have failed to show differences in boundary location identified across groups differentiated by hearing status or age Nábělek et al (1993) compared boundaries exhibited by adult participants with normal hearing and adult participants with a hearing impairments Five stimulus types were examined, steady-state formants, F1 up, F1 down, F1 and F2 up, and F1 and F2 down Variants on the steady-state continuum were differentiated by the frequency of the first formant The range of frequencies were from 360 to 580 Hz The average 50% response for steady-state vowels presented in quiet for adults with normal hearing group was at 8 14 and had an F1 of 468 Hz The boundary location exhibited by adult participants in the present study was 5 99 and had an F1 of 450 Hz Boundaries between vowels on a continuum have also been identified in children In Walley and Flege's study (1999), using one lax and one tense vowel ([ɪ] and [i], respectively) location of boundary was not statistically different among two groups of children (i e , 5-year-olds and 9-year-olds) and one group of adults. The present study parallels Walley and Flege's finding using two lax vowels: No statistically significant difference was found among the three groups of participants Categorization skills appear to develop early Using a change versus no-change paradigm, Marean et al (1992) reported that categorization skills are evident in infants as young as 2-months old It is the refinement of these skills that the present study is investigating

Although boundaries did not differ among groups, every participant identified variants around their boundary with less certainty than those near the endpoints Goodness of fit theory postulates that variants near a prototype are less discriminable than those near a boundary In the present study, average slopes at the boundaries were more steep than slopes at both the 75% response point and the 10% response point for all three groups This provides modest support for goodness of fit theory Tokens near the endpoints were more consistently labeled than those near the boundaries Both individual and group figures of [ɪ] responses as a function of token number demonstrate that variants near the endpoints were more easily categorized than those near the boundary

Slope

To evaluate the development of categorical perception skills as children mature, slopes at the categorical boundanes were analyzed For the best support of this process, the slopes would get progressively steeper as children mature In the present study, a statistically significant difference in variance of slopes was found between the younger children and adults No difference was noted between the older children and either of the two remaining groups of participants However, a general trend was noted that as age progressed, the slope at the boundary increased in steepness This finding is consistent with Walley and Flege's (1999) finding This suggests that as children mature, their efficiency ın categorical perceptıon improves

Research with Japanese listeners (Takata, 1991) has shown that time exposed to a non-native language (ı e , Englısh) while ın the United States does not affect categorical perception In Takata's study, 2 of the 30 Japanese listeners who had spent the most time in the United States (i e., 5 years 3 months and 3 6) exhibited more shallow slopes than three Japanese listeners who had spent less time in the United States (i e., 1, 3, and 4 months) This suggests that categorical perception may not be exclusively a learned skill but also subject to indıvidual aptitude However, listeners who performed well in the categorıcal perception task in quiet exhibıted difficulty categorizing in the presence of noise In this condition, the subjects exhibited immature categorical skılls Therefore, categorical perception skills may be a product of indıvidual aptitude as well as learning

Some participants in the present study exhibited poor categorıcal perception when compared to participants within the same group Three children ın the younger child group exhibited slopes at the boundary similar to those exhibited by older children and adults These children were good categorizers Inversely, two of the children in the older child group and one adult exhibited slopes at the boundary similar to those of the younger children These participants were poor categorizers

Good categorizers in the younger child group exhibited language scores similar to other members within their group None of the children in this group had entered first grade, so it is assumed that all participants had little experience to formal reading instruction. However, one parent reported that her child enjoys reading Based on the available information, it is unclear if any or all of these children were independent readers

A poor categorizer in the older child group exhibited a slope below minus one standard of the mean for the group Although her language scores were in the lower range of normal limits, they were paralleled by other members within the same group It is unlikely that her language ability accounted for her poor categorizational skills

If participants who were poor categorizers were not using categorizational skills to perceive the vowels, then one may speculate that perhaps they were using anchors at the boundary The data from the present study does not support this It may be that the poor categorizers in the present study lacked a stable representation to use as a referent when categorizing vowels

Formal Reading Instruction

When considering the differences between the two groups of children participating in the present study, one factor is clearly evident Formal instruction in reading Most curricula are structured such that reading is taught during the early elementary school years By the end of third grade, most students have mastered reading well enough to use reading as a mode of learning in other areas Thus, it is about this time that new subjects are introduced to students in printed textbooks such as, social studies, English, and science All of the children in the younger group in the present study had not yet entered first grade in school and are assumed to have little explicit instruction in reading Therefore, their more shallow slope may be a result of this lack of instruction However, phonological awareness has been shown to correlate with reading abilities More shallow slopes may be correlated with phonological awareness abilities. This correlation between phonological awareness skills of the participants in the present study will be discussed in the following section

Language Abilities

Elliott et al (1989) found a correlation between auditory discriminative ability and language ability in 6- and 7-year-old children Since all of the children in the present study were given language assessments and scored above one standard deviation when compared to same-age peers, language abilities should not be a factor However, there was variance among the language scores of the children The range of standard scores for the receptive portion of the CELF-3 or the CELF-P were from 86 to 143 The expressive portion of these tests yielded a range in standard scores from 88 to 126 and the total language standard scores ranged from 88 to 125 Standard scores for the compounds and syllables portion Deletion subtest of the PAT are not available for older children (this test is not normed for children above the age of 9 11) However, ranges of standard scores for younger children on compound portion were 92 to 123, for the phonemes portion, 97 to 126, and for the complete subtest, 95 to 123 Accuracy scores on the Deletion subtest of the PAT ranged from 80 to 100% for the older children and 55 to 85% for the younger children

To investigate the possibility that language ability contributed to steepness of slope, a multi-variate analysis was conducted to examine measures taken during the first session for inclusion in the study The following test measures were analyzed; receptive language score, expressive language score, and percent correct on deletion subtest of the PAT The correlational analysis yielded one factor that highly correlated with the steepness of slope for both groups of children That factor was the percent correct on the deletion subtest. As the percentage of correct responses increased, so did the steepness of slope

Phonological awareness has been shown to be a predictor later literacy skills (e g , Stackhouse, 1997) Specifically, performance on a deletion task in kindergarten has been correlated with children's ability to read a list of real and pseudo-words in first grade (Catts, 1991) While phoneme deletion is but one area targeted in a phonological awareness program, it appears to have been related to the outcome of the slopes in children in the present study If this is the case, then is the ability to categorize efficiently a precursor to phonological awareness and later literacy skills, or is the ability to categorize efficiently a by-product of phonological awareness?

Categorical perception has been tested in school-age children (i e , 8-14 years of age) with and without a reading disability (Werker & Tees, 1987) Children without a reading disability exhibited better categorical perception on a continuum between two CV syllables differentiated by place of articulation (i e , /ba/ and /da/) If children with reading impairments are less efficient in categorical perception compared to same-age peers, then could this lack of efficiency be the underlying mechanism of the reading disability? If so, can anything be done to improve categorization skills and thus improve phonological awareness?

Training Perception

The ability to categorize has been shown to improve as the result of training. Guenther, Husain, Cohen, and Shinn-Cunningham (1999) have demonstrated improvement of categorization and discrimination skills in adults using non-speech sounds as a result of training in listening. A prototype category was introduced to participants during a training phase. Participants had to choose the only prototype category sound from a list of sounds. The stimuli were narrow-band filtered white noise which varied in frequency at the centers. In a second task, participants listened to four sounds that were variants in the region of the prototype category. After a single 1.5 hour session, sensitivity worsened for the sounds within the prototype category. This phenomena is called induced acquired similarity.

Improvement in perception of CV and VCV syllables has been demonstrated in children (e.g., Merzenich et al., 1996). Using a computer game format, children's temporal processing improved as a result of training. In the first game, a perceptual identification task, 5.9 to 9.1-year-old children with language-based learning impairments were required to reproduce the order of two stimuli sound sequences. Stimuli used were non-speech sounds. In a second game, phonetic element recognition, children were presented two CV stimuli in rapid sequence. Children identified the position in the sequence of a precued target syllable. Both games began with stimuli that could be easily distinguished (e.g., long durations, long inter-stimulus intervals, and amplification of the consonant transition) Throughout training, these variables were slowly altered to approximate normal performance levels Improvement was noted in almost all of the children (five out of seven on the first task and six out of seven on the second task)

Phonological discrimination and language comprehension have been shown to improve in children with a language impairment as a result of training (Tallal et al , 1996) Using temporally modified speech to train children, the researchers found an improvement between pre- and post-test scores in children exposed to training for six weeks These results were based on CV pairs which differed in the consonant (/b/ versus /d/) While these stimuli may be modified temporally (transitions lengthened), they may not be exclusively testing temporal perception Studdert-Kennedy and Mody (as cited in Leonard, 1998) suggest that Tallal's work on temporal processing looks at CV pairs which may be influenced not only by stimulus duration and rate of presentation but also by place of articulation and direction of trajectories These pairs may not accurately assess temporal processing However, if using modified speech does improve phonological discrimination, then perhaps this training may exhibit an effect on categorization skills

Comparison of Slope with Previous Work

A secondary purpose of this study was to see if results parallel those previously reported (Nábělek et al., 1993, Walley & Flege, 1999) The former work examined slopes at the boundary location for two groups of listeners (i e , normal-hearing and hearing-impaired) across three listening conditions (i e , in quiet, in reverberation, and in noise)

Additionally, five stimulus types were used, steady-state formants, F1 up, F1 down, F1 and F2 up, and F1 and F2 down Since the stimuli in the present study were all steady-state presented in quiet to participants who exhibited normal hearing, only these conditions are compared The present study found a slope at the boundary for adult participants of 0 416 The previous work by Nábělek et al (1993) found a slope at the boundary of 0 40 These slopes appear to parallel one another

Walley and Flege (1999) used narrow-range PROBIT analyses to fit a cumulative normal curve to raw data Slopes were determined by 1/s d (Best & Strange, 1992) Slopes for 5-year-olds, 9-year-olds, and adults on an [i] to [ɛ] continuum were 0 35, 0 82, 1 39, respectively A direct comparison of the present results with this previous work is not possible due to differing analysis processes However, the results of both studies show that slopes increase with advancing age Although the continuum used in the Walley and Flege study and the continuum used in the present study use different vowel at the endpoints, on both continuua, a steepening of slope is seen with maturity

Endpoints

Responses for endpoints (i e., tokens 1 = [ɪ] and 14 = [ɛ]) were the most predictable Since these tokens were used in training the subjects, it was assumed that they would be identified appropriately with near 100% accuracy However, this was not the case Adults identified endpoints with near perfect accuracy (i e , 99%) Older children identified endpoints with 96 5% accuracy, and younger children with 87 5% accuracy The two adults who misidentified an endpoint, participants number 09 and 10, also exhibited the two most shallow slopes in the adult group (i e , 0 142 and 0 309, respectively) The same held true for the two participants who exhibited the two most shallow slopes in the older child group However, a third child who misidentified an endpoint exhibited a slope (0 327) above the group mean (0 299) Five of the children in the younger child group misidentified endpoints The slopes exhibited by these children represent the most shallow of the young group of children Additionally, all of these slopes were below the mean for the group

Within the group of younger children who misidentified some of the endpoints, individual variations in responses can be found One of the children who misidentified the most endpoints (participant number 02), exhibited relatively stable responses on tokens number 10, 11, and 12, with only one deviation in response (i e , responded [ɛ] in 29 out of 30 trials on token numbers 10, 11, and 12) Another child (08) who had the same number of endpoint misidentifications (seven), was less stable in all of her responses She did not respond 100% to any of the tokens on the continuum One participant in the younger child group (09) only made three errors on endpoint identification However, he exhibited fairly stable responses (90% consistent identification rate) on two tokens (numbers seven and eight) which bounded his 50% response point (7 256) A fourth child in the younger child group (03) misidentified only three endpoints, but only showed stability near the [ɪ] end of the continuum (i e , he consistently identified tokens number two, three, and four, as [ɪ]). This consistency was not noted at the other end of the continuum

A total of 34 endpoints were misidentified across the three groups of participants To determine if attention affected the results in the present study, endpoint misidentification was examined as a function of presentation block. There were 10 blocks of presentations with 14 stimuli in each block Blocks 1 through 5 constituted the first half of the experiment Blocks 6 through 10 constituted the last half of the experiment Twelve (35 3%) of these endpoints were misidentified during blocks 1 to 5 The remaining 22 (64 7%) occurred during the last five blocks While this suggests that attention may have been a factor in endpoint identification, further analysis reveals that attention was not a factor Only 22 of the 300 were misidentified during the last five blocks Adults missed only two endpoints in the entire experiment, one [ɪ] and one [ɛ], both of which were in the last five blocks Older children missed token 1 equally in the first and last half of presentations However, they missed token 14 exclusively in the last half of presentation trials Younger children missed token number 1 twice in the first half of trials and eight times in the last half of trials However, misidentifications of token number 14 were similar in both halves of trials (first half = 8, second half = 7) In examining these trends, it is unlikely that attention influenced endpoint identification especially with [ɛ] in younger children and [ɪ] in older children Given that attention was not a factor in endpoint identification, then the present author feels that attention had little effect on overall results

Clinical Relevance

Based on the correlation between the deletion task in phonological awareness and steepness of slope, categorical perception abilities may have a relationship with reading abilities If efficient categorical perception is a precursor to later literacy skills, then a component targeting efficient categorical perception could be added to early literacy instruction Improvement in categorical perception skills may facilitate the development of reading ability Additionally, children with language-learning difficulties may benefit from this added component to literacy instruction These children typically need more exposure to linguistic structures and more time for processing the added information

If categorical perception proves to be a predecessor for later reading ability, then categorical perception skills may also be used to predict later literacy skills or the child's readiness to learn to read These skills could be evaluated and at-risk students could be identified Once again, training could be employed to improve these skills to facilitate improved reading ability

Limitations

The current study has several limitations The first is related to the sample of participants The sample was not representative of the population at large in terms of race, socio-economic status, and gender All of the participants were Caucasian, presumably middle to upper-middle class This is evident by occupations of parents listed on questionnaires. Occupations of the fathers of the children included, a city judge, emergency physician, an architect, a college professor, two attorneys, a police officer, a welder, vice president of a brokerage firm, service manager, a merchant/owner, a quality engineer, a film buyer, a claims representative, an electrician, a sales manager, and a laborer Seven of the mothers of the children report that they are homemakers and community volunteers The remaining mothers include, two nurses, an attorney, a finance advisor, two claims representatives, an educational therapist, a teacher, a clerk, and a factory worker Thirteen of the children live in homes with both parents

The adult group consisted entirely of female participants The two groups of children had unequal ratio of girls to boys (i e, younger children = 3 girls and 7 boys, older children = five girls and five boys) Gender was not controlled and therefore may have influenced the results

Dialect was not controlled for in this study With the exception of three child participants, parents of the children reported that all members of the household spoke Standard American English The parents of the three remaining children reported that Appalachian English is spoken by some family members Adult participants also reported dialectical variations Seven adults reported speaking Standard American English, while three reported speaking Appalachian English

Another factor related to subjects not controlled in this study was the exposure of the participants to formal instruction Although not reported on questionnaires, through interviews, the children reported that some attend private schools, others attend public schools, and two of the children were home-schooled Although it may be assumed that the state curriculum in Tennessee is taught to all children, several of the children have lived in other states including, Colorado, Idaho, Connecticut, Ohio, Virginia, North Carolina, and Texas

A second limitation of the present study relates to the stimuli Although it has been shown that synthetic stimuli are suitable for speech perception research, the synthetic stimuli do not have the same characteristics as speech produced naturally. Additionally, the present study uses stimuli presented in isolation Typically, in English, letters in isolation are only used when spelling words CVC constructs may be a better representative of natural speech

Finally, time was not controlled for in the present study Children varied in the time needed to provide responses Additionally, some children needed more time during the break to speak to their mothers or to go to the restroom This was permitted to ensure high levels of attention to task One child upon returning to the booth, requested immediately to return to the restroom, making her break fifteen minutes instead of five minutes While positive verbal feedback was given randomly once per block of presentations, some children had difficulty staying on task

Future Research

Categorical Perception and Literacy

As suggested previously, future research should attempt to investigate the relationship between categorical perception skills and emerging and developing literacy skills Attempts to define this relationship should include differentiating which develops first, efficient categorization or literacy This could be accomplished by examining younger children and following them through a longitudinal study Ideally, pre-readers (approximately 4-years-old) would be selected and followed until literacy skills are developed (approximately second grade) Relevant measures which could be monitored at regular intervals would include, phonological processing skills, categorical perception skills (as demonstrated in this study), and literacy skills By examining these measures in a longitudinal study, the direct relationship between categorical perception and reading should be defined

Categorical Perception and Children with Language-Learning Difficulties

Future research should also include examining the categorical perception skills of children with language-learning difficulties across several ages In a younger school-age population, this information may be used to plan and implement strategies which may improve later literacy skills In older school-age children with language-learning difficulties, it may improve our understanding of the deficits these children experience

Replication with Stimuli Based on Varying Voices

The present study used data from Peterson and Barney (1952) as a basis for acoustic parameters of the stimuli (F1, F2, and F3) These standards were based on a male speaking voice The two endpoint tokens were plotted on a graph of the frequency of the second formant as a function of frequency of the first formant This graph was based on average frequencies across 76 speakers, 33 men, 28 women, and 15 children Both of the endpoints of the present study fell within Peterson and Barney's (1952) corresponding vowel spaces Gender differences in the acoustic properties of the stimuli should not be problematic After all, speaker normalization due to intrinsic specification is based on acoustic information inherent to the vowel (Neary, 1989) Future research could address not only gender differences in acoustic properties of stimuli but also, age differences Perhaps, three listening conditions could be tested One in which the stimuli are based on a male speaker, a second based on a female speaker, and the last based on a child speaker

Replication Using Other Vowels

The present results parallel the findings of Walley and Flege (1999) using two lax vowels However the results of this study should be replicated using other vowels, possibly back vowels (e g , [ʊ] and [ɑ]) Additionally, categorical perception of vowels on a continuum differentiated by the second formant should be investigated

Replication with Younger Children

Walley and Flege (1999) used CVC constructs in their categorical perception research They found that using a continuum with real words as endpoints, slopes were steeper Categorical perception may be influenced by lexical experience which contributes to the stability of representations. Walley (1993) reports that early perception is "holistic" and segmental in nature Therefore, younger participants who have less stable representations may exhibit difficulty when presented tasks testing this ability However, using the two vowels from the present study and placing them in similar constructs described by Walley and Flege (1999) may simplify the task so that even younger children may participate This would further define the development of categorical perception

Summary

This study supported recent findings that categorical perception is a developmental process that becomes refined as children mature However, some of the responses of the younger children in this study mirrored those of older children and adults Reasons for this phenomena were explored and discussed One idea is that at the same time that refinement of categorical perception skills is occurring, children are exposed to formal literacy instruction Formal literacy skills can be predicted by phonological awareness skills of the child In the present study, a correlation was noted between one area of phonological awareness and the refinement of categorical perception skills in school-age children.

With future research into this relationship, the implications of these findings may lead to a new component being added to the therapeutic process By training categorical perception skills, literacy skills may also improve Additionally, with future research, it may be possible to predict literacy skills based on categorical perception skills This could become a valuable tool in early identification of children at-risk for later difficulties

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APPENDICES

APPENDIX A

Adult Questionnaire

ADULT QUESTIONNAIRE

I. Participant Information

Name ______________________ Age __________ Gender ☐ Male ☐ Female

Address ____

City ______________________ State ____________ Zip ______

Phone ____

Have you lived in East Tennessee for your entire life? ☐ YES ☐ NO

If no, please specify where the you have lived. ______________________

Are your parents natives of East Tennessee? . . . ☐ YES ☐ NO

If no, please specify ____________________________________

2. Communication Information

Have you ever received services for speech, language or hearing difficulties? . ☐ YES ☐ NO

If yes, explain ____________________________________

During your childhood, was English the only language spoken in your home? ☐YES ☐NO

If no, please specify ____________________________________

Mark the box which best describes your dialect

☐ Standard American English

☐ African-American English

☐ Regional variation of Standard American English indicative of East Tennessee

☐ Other, please specify ____________________________________

APPENDIX B

Fact Sheet

FACT SHEET FOR

Boundary of Steady State Synthetic Vowels [ɪ] and [ɛ] in Adults and School-age Children

Ms. Susan L. Pursell
Dr. Lori A. Swanson
The University of Tennessee, Knoxville

Site of Testing	Child Language Lab (Room 432 South Stadium Hall) and Perception Lab (Room 557 South Stadium Hall) at UTK
Time of Testing	Summer 1999 - Spring 2000
Tasks	1) hearing evaluation and articulation screening test, 2) language evaluation, 3) vowel discrimination task, and 4) sentence production task
Length of Testing	Child participants· Two one hour sessions Adult participants Single one hour session
Test Administrators	Tests will be administered by Ms Susan Pursell or Dr. Lori Swanson
Vowel Discrimination task	The participants will be asked to listen to sounds and decide whether they hear an [ɪ] as in "hid"or an [ɛ] as in "head"
Sentence Production task	Participants will be asked to produce short sentences containing the vowels [i] as in "heed", [ɪ] and [ɛ]
Number of Participants	Approximately ten adults, ten 5- and 6-year-old, typically developing children, and ten 10-year-old, typically developing children
Approval for the Study has been obtained from	The University of Tennessee-Knoxville
Benefit of Project	Information obtained from this study will be used to instruct speech-language pathologists in young children's development of speech perception skills It is hypothesized that 5- and 6-year-old children will show less mature patterns than 10-year-old children
For Additional Information Call	Lori A Swanson, Ph D or Susan L Pursell (423) 974-1794 University of Tennessee-Knoxville

APPENDIX C

Informed Consent for Adult

Informed Consent for Adult

Boundary of Steady State Synthetic Vowels [ɪ] and [ɛ] in Adults and School-age Children

Ms. Susan Pursell

Dr. Lori A. Swanson

The University of Tennessee, Knoxville

The purpose of this study is to investigate the category boundary between [ɪ] and [ɛ] defined by adults and children Three groups of participants will participate in this study One group will be college students, another will be typically developing five- and six-year-old children and the last will be typically developing ten-year-old children. A comparison of results obtained from each group will provide information related to the development of categorical perception of vowels

Adults will be scheduled individually for a single one-hour session at the subjects' convenience Sessions will be held at the Child Language Laboratory (Room 432 South Stadium Hall) At the beginning of the session, a hearing screening will be performed. Subjects with normal hearing will then listen to the experimental task

First, participants will listen to 14 tokens on a continuum from [ɪ] to [ɛ] presented ten times each for a total of 140 test trials These tokens differ in the frequency of the first formant Stimuli will be presented at a loudness level comparable to that of an average person speaking in normal conversation Upon presentation of each stimulus, participants will be asked choose between the two vowels and make an appropriate mark on a response form A break will be provided midway through the presentation trials Additional short breaks will be provided if the participant becomes fatigued. Second, participants will produce approximately 45 short sentences containing the [i], [ɪ], and [ɛ] vowels These productions will be audio recorded.

The experimental data gathered will be maintained in confidential files in the office of the faculty advisor (room 431 South Stadium Hall) at UTK and will be identified by code number on all test and response forms Your name will not appear in any presentations of publications that may follow No one will have access to the individual results of this investigation other than the principal investigator, faculty advisor, and two members of the faculty in the Department of Audiology and Speech Pathology at UTK involved with the study These faculty members are Dr Mark Hedrick and Dr Anna Nábělek. If you have any questions concerning this study, please feel free to call the faculty advisor (Dr Lori Swanson) at the following number: (423) 974-1794

The procedures have been explained to me, I understand and voluntarily agree to participate. I am aware that I may withdraw from this study at any time without penalty or discrimination. Lack of participation will not affect any current or future contact I may have with the University of Tennessee Hearing and Speech Center or my academic progress as a student within the Department of Audiology and Speech Pathology.

Signature ______________________________ **Date** ______________________________

Name ______________________________ **Birthdate** ______________________________

I prefer to be contacted at: ______________________________
(Phone, e-mail, USPS, etc)

APPENDIX D

Informed Consent for Child

Informed Consent for Child

Boundary of Steady State Synthetic Vowels [ɪ] and [ɛ] in Adults and School-age Children

Ms. Susan Pursell

Dr. Lori A. Swanson

The University of Tennessee, Knoxville

The purpose of this study is to investigate the category boundary between [ɪ] and [ɛ] defined by adults and children. Three groups of participants will participate in this study. One group will be college students, another will be typically developing five- and six-year-old children and the last will be typically developing ten-year-old children. A comparison of results obtained from each group will provide information related to the development of categorical perception of vowels.

Children will be scheduled individually for two one-hour sessions at the parents' convenience. Sessions will be held in the Child Language Laboratory (Room 432 South Stadium Hall). During the first session, children will be evaluated to see if they qualify for this study. Testing procedures will include a hearing screening, articulation screening, and an evaluation of participants' language abilities. All tests which will be administered are speech and hearing evaluations which have no known risks greater than those involved in normal daily activities. This session will be audio recorded.

During the second session, two experimental tasks will be administered. First, children will listen to 14 tokens on a continuum from [ɪ] to [ɛ] presented ten times each for a total of 140 test trials. These tokens differ in the frequency of one signal component. Stimuli will be presented at a loudness level comparable to that of an average person speaking in normal conversation. Upon presentation of each stimulus, participants will be asked choose the vowel they perceived and point to an appropriate picture. Several short breaks will be provided during the presentation trials. Additional short breaks will be provided if the participant becomes fatigued. Second, participants will produce approximately 45 short sentences containing the [i], [ɪ], and [ɛ] vowels. These productions will be audio recorded.

The experimental data gathered will be maintained in confidential files in the office of the faculty advisor (room 431 South Stadium Hall) at UTK and will be identified by code number on all test and response forms. Your child's name will not appear in any presentations of publications that may follow. No one will have access to the individual results of this investigation other than the principal investigator, the faculty advisor, and two members of the faculty in the Department of Audiology and Speech Pathology at UTK involved with the study. These faculty members are Dr. Mark Hedrick and Dr. Anna Nábělek. If you have any questions concerning this study, please feel free to call the faculty advisor (Dr. Lori Swanson) at the following number (423) 974-1794.

The procedures have been explained to me, I understand and voluntarily agree to allow my child to participate. I am aware that at any time, I may withdraw my child from this study without penalty to me or my child. Additionally, my child may withdraw from this study without discrimination. Lack of participation will not affect any current or future contact I may have with the University of Tennessee Hearing and Speech Center.

Parent/Guardian ______________________________

Signature ______________________ **Date** ______________________

Child's Name ______________________ **Child's Birthdate** ______________________

APPENDIX E

Child Questionnaire

CHILD QUESTIONNAIRE

I. Participant Information

Child's name ______________________ Birthdate ________________ Sex _______

Address ____

City ______________________________ State ________________ Zip _______

Phone ____

II. Family Information

Father's name: ___________________________ Occupation ________________

Mother's name. ___________________________ Occupation ________________

Does child have brothers and/or sisters? ☐ YES ☐ NO

If yes, specify ages ____

Has the child lived in East Tennessee for his/her entire life? . . ☐ YES ☐ NO

If no, please specify where the child has lived _______________________________

Are parents natives of East Tennessee? . . . ☐ YES ☐ NO

If no, please specify ____

For each person who lives in the home with the child, please list their relation to the child and then mark the box which best describes their dialect

Relation to Child	Standard American English	African-American English	Appalachian English	Other
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐

III. Communication Information:

At what age did your child say single words? ____________________

At what age did your child say 2-3 word sentences? ____________________

Has child received services for speech and/or language difficulties? . ☐ YES ☐ NO

If yes, explain ____________________

Is English the only language spoken in the home? . . . ☐ YES ☐ NO

If no, please specify ____________________

IV. Medical Information

Were problems experienced during pregnancy, delivery, or post-partum? ☐ YES ☐ NO

If yes, explain ____________________

Was there any difficulty with feeding the child during infancy? . ☐ YES ☐ NO

If yes, explain ____________________

Is your child taking any medication regularly? . ☐ YES ☐ NO

If so, please list ____________________

Does your child have a history of ear infections? . . ☐ YES ☐ NO

If yes, please explain____________________

V. Developmental / Social Information

At what age did your child sit alone __________ crawl __________ walk __________

How does your child get along with familiar adults? ____________________

____________________ Unfamiliar adults? ____________________

What activities does your child enjoy? ____________________

What activities does your child dislike? ____________________

VI. Preschool / School Information

Please mark the appropriate box that describes your child's current status

☐ elementary school, ☐ nursery, ☐ daycare, ☐ preschool

If your child attends elementary school, what is his/her current grade? ____________

Does your child receive any special services (speech therapy, learning resource, special school class, etc)? . . . ☐ YES ☐ NO

If so, please describe ____

Has your child successfully passed each grade attempted at school? . . ☐ YES ☐ NO

Person completing this form____

Relationship to child ______________________________ Date ______________________

APPENDIX F

Assent Form for Children

Assent Form for Children

Boundary of Steady State Synthetic Vowels [ɪ] and [ɛ] in Adults and School-age Children

(The following script will be used when obtaining an audio recording of the child's assent)

Hello, my name is (Lori or Susan) I would like for you to listen to some sounds and point to a picture that shows what you hear It's sort of like a game, All you have to do is listen and point If you do not want to do this, then that is okay Just tell me Would you like to help me with my project?

Great! Are you ready to listen to some sounds? Let's begin by checking your hearing

Thank you!

APPENDIX G

Results of Child Assessments

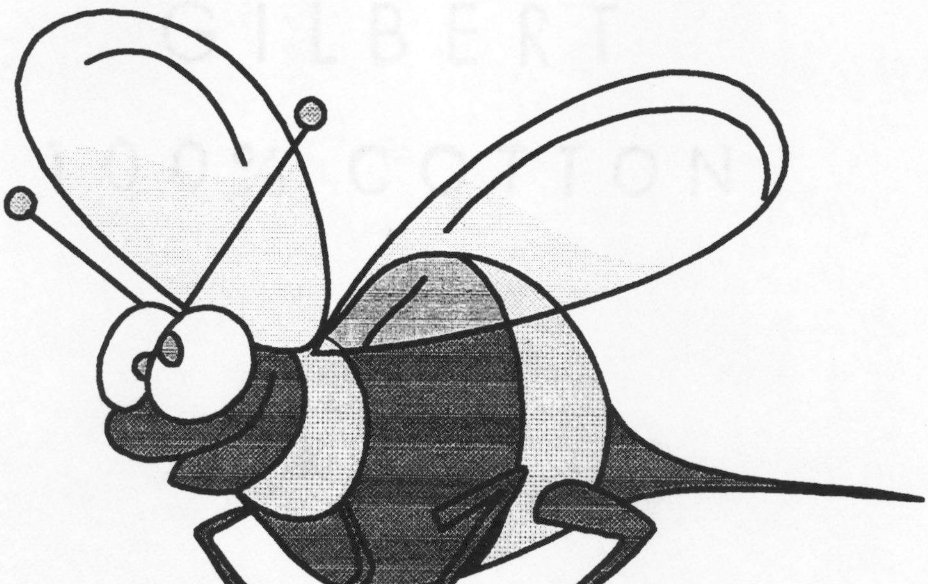
Table A-1 Individual scores for first-session assessments for child participants

	AGE	GENDER	RL	EL	TL	PAT SYL	PAT PHO	PAT TOT	PAT % ACC
OC 01	10 4	M	104	104	104	NA	NA	NA	80
OC 02	10 7	F	86	92	88	NA	NA	NA	80
OC 03	10 2	F	118	112	115	NA	NA	NA	95
OC 04	10 1	M	102	100	101	NA	NA	NA	100
OC 05	10 4	M	125	108	117	NA	NA	NA	95
OC 06	10:0	F	90	90	89	NA	NA	NA	100
OC 07	10 0	M	96	94	94	NA	NA	NA	80
OC 08	10 1	F	135	122	130	NA	NA	NA	100
OC 09	10 2	F	100	88	93	NA	NA	NA	90
OC 10	10 11	M	143	106	125	NA	NA	NA	90
YC 01	6 2	F	106	90	97	107	119	115	85
YC 02	6 8	M	108	94	101	114	100	106	75
YC 03	6 0	M	106	100	103	92	98	95	55
YC 04	5 11	F	118	104	111	104	111	110	60
YC 05	6 0	F	94	122	108	92	119	109	75
YC 06	5 8	M	114	108	111	111	126	123	80
YC 07	6 0	F	128	112	121	99	104	102	65
YC 08	5 10	F	110	126	118	123	107	116	70
YC 09	6 2	F	102	88	94	114	97	107	55
YC 10	5 9	F	114	104	109	111	126	123	80

OC = Older Children group, YC = Younger Children group, RL = Receptive Language Score, EL = Expressive LanguageScore, PAT SYL = Standard Score on compounds and syllables portion of Deletion subtest of PAT, PAT PHO = Standard Score on phonemes portion of Deletion subtest of PAT, PAT TOT = Standard Score on Deletion subtest of PAT, PAT % ACC = Percentage correct on Deletion subtest of PAT

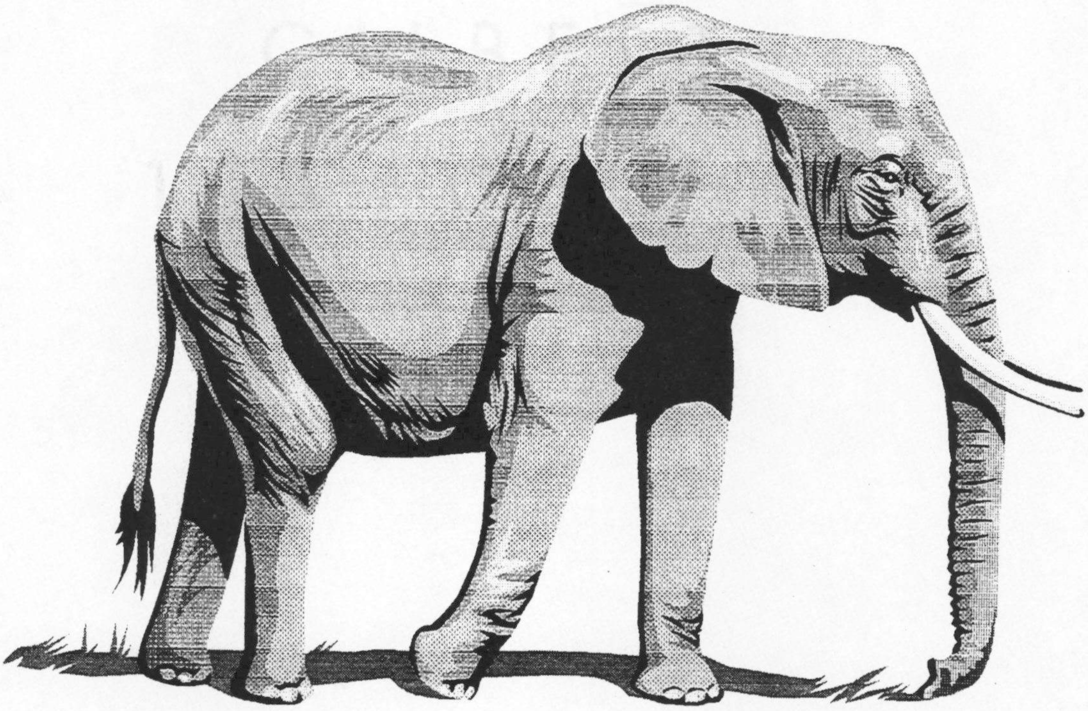
APPENDIX H

Picture of Insect



APPENDIX I

Picture of Elephant



APPENDIX J

Instructions for Children

Instructions for Children

Hi <child's name> I'm <researcher's name> Do you remember me from last time?
Child responds
We're going to do something different today We're going to listen to sounds Do you like to wear headphones when you listen to music?
Child responds
Good, then you'll like listening to these sounds
[investigator places headphones on participant and on self]
Now let's listen to some sounds Are you ready?
Child responds
Listen to this
[researcher plays [ɪ]]
That was the "insect" sound Let's try that one again
[researcher repeats presentation of [ɪ]]
Look, here is a picture of an insect When you hear the "insect" sound, point to this picture Are you ready?
Child responds
Here it comes!
[researcher repeats presentation of [ɪ] and after brief delay to allow child to point, researcher points to the picture of the insect]
Good job, now you try by yourself
[Researcher repeats presentation of [ɪ] and waits for child to respond If child does not respond, repeat previous dialogue]
Let's listen for another sound. Are you ready?
Child responds
[researcher plays [ɛ]]
That was the "elephant" sound. Let's try that one again
[researcher repeats presentation of [ɛ]]
Look, here is a picture of an elephant When you hear the "elephant" sound, point to this picture Are you ready?
Child responds
Here it comes!
[researcher repeats presentation of [ɛ] and after brief delay to allow child to point, researcher points to the picture of the elephant]
Great! Now you try it by yourself
[Researcher repeats presentation of [ɛ] and waits for child to respond If child does not respond, repeat previous dialogue]
Wow! You heard the "elephant" sound
Let's try something fun Listen to this sound
[researcher plays [ɪ]]
Did you hear the "insect" sound or the "elephant" sound? Point to the picture of the sound you heard
Child responds
[Repeat stimulus if child requests it If child answers inappropriately, then repeat stimulus and provide a model for appropriate response. If child answers appropriately, then continue with dialogue]
Good job! Let's try another
[researcher plays [ɛ]]
Did you hear the "insect" sound or the "elephant" sound? Remember to point to the picture
Child responds

[Repeat stimulus if child requests it If child answers inappropriately, then repeat stimulus and provide a model for appropriate response If child answers appropriately, then continue with dialogue]

Let's try one more, okay?

Child responds

[researcher plays [ɛ]]

Did you hear the "insect" sound or the "elephant" sound? Remember to point to the picture

Child responds

[Repeat stimulus if child requests it If child answers inappropriately, then repeat stimulus and provide a model for appropriate response If child answers appropriately, then continue with dialogue]

You're doing a great job Now I'm going to play more sounds When you hear a sound, point to the picture of that sound. It will be hard to choose a picture for some sounds But if you don't know which one you hear, it is okay to guess Are you ready?

Child responds

Remember to point to a picture after every sound Here goes

[Begin stimuli presentation tape for experimental data collection randomly giving positive verbal feedback once during each set of ten presentations After twenty presentations, pause the tape and allow child to choose a sticker]

[After 70 presentations, stop for a break]

You're working hard! I think it's time for a short break. Would you like a drink of water?

[Provide water if desired. Allow child to stand and stretch After five minutes, redirect child to task repeating instructions previously given]

You're doing a great job! Let's continue Remember when you hear a sound, point to the picture of that sound Are you ready?

Child responds

[Play remainder of stimuli providing verbal reinforcement once during each set of ten stimuli and providing an opportunity for child to select a sticker after each set of twenty presentations]

We're finished! You did a great job! Thanks for your help Would you like to choose a prize from my prize bucket?

APPENDIX K

Instructions for Adults

Instructions for Adults

Hi <participant's name> I'm <researcher's name> Thank you for helping me today I'm going to play a sound and I would like for you to listen

[researcher plays [ɪ]]

That was an [ɪ] I'm going to play it again and this time I would like for you to circle the "[ɪ]" on your response form

[researcher plays [ɪ]]

Great! Now listen to [ɛ]

[researcher plays [ɛ]]

This time, when you hear [ɛ] circle "[ɛ]" on your response form

[researcher repeats presentation of [ɛ]]

Now you are going to hear more sounds You will hear seventy presentations of these vowels When you hear a stimulus, circle the appropriate symbol on your response form Some of the stimuli will be difficult to discriminate If you are unsure about a stimulus, it is okay to guess Do you have any questions before we begin?

Participant responds

[Researcher answers all questions asked.]

Are you ready to begin?

Participant responds

[After presentation of seventy stimuli, stop task for a five minute break.]

I think it is time for a short break. Would you like to get a drink of water?

Participant responds

[Provide water if desired. Allow participant to stand and stretch After five minutes, redirect participant to task]

You're doing a great job! Are you ready to continue?

Participant responds

Remember to circle a symbol when you hear a sound. Are you ready?

Participant responds

[Play remainder of stimuli]

You're finished! Thanks for your help Do you have any questions?

Participant responds

Thanks again and have a nice day

APPENDIX L

Response Form

Response Form

/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	
/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	/ɪ/ or /ɛ/	

APPENDIX M

Raw Data

Adult 01

Block 1	4	5	3	11	8	10	14	1	9	2	7	13	12	6
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 2	9	4	13	6	8	7	14	1	12	2	11	10	3	5
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 3	12	14	9	10	5	6	11	4	3	2	13	7	8	1
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 4	4	1	10	11	5	6	8	7	3	9	12	14	13	2
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 5	8	9	11	6	5	10	3	2	7	12	1	13	14	4
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 6	8	3	7	13	2	5	1	14	10	4	9	11	6	12
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 7	12	3	2	10	9	11	14	5	13	8	7	1	6	4
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 8	3	7	9	14	12	10	11	6	2	1	13	4	5	8
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 9	13	9	7	2	5	11	8	14	12	1	4	10	3	6
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 10	9	8	12	3	10	5	11	7	4	13	2	6	14	1
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/

Adult 02

Block 1	4	6	12	1	5	11	3	13	8	10	9	7	2	14
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 2	13	7	1	8	14	11	2	12	4	10	5	9	3	6
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 3	13	7	3	14	10	8	2	12	9	1	4	5	6	11
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 4	10	8	13	9	3	1	6	2	11	4	5	7	14	12
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 5	5	11	12	1	7	4	10	8	13	6	14	3	9	2
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 6	8	13	7	9	5	1	14	12	3	2	11	6	4	10
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 7	7	12	3	4	2	13	10	8	11	1	14	5	6	9
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 8	3	4	10	2	13	8	5	11	1	7	6	9	14	12
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 9	4	8	1	3	10	6	7	11	14	2	9	13	5	12
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 10	9	7	4	5	3	12	10	13	8	11	6	14	2	1
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/

Adult 03

Block 1	7	12	13	3	9	10	4	1	2	14	8	6	11	5
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 2	6	13	11	7	9	10	4	3	8	14	2	5	12	1
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 3	13	8	10	1	14	4	6	3	2	12	5	7	11	9
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 4	6	12	10	1	8	7	3	13	2	9	11	14	4	5
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 5	14	7	10	13	8	4	11	3	1	12	5	2	9	6
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 6	13	9	4	12	8	7	10	2	14	6	11	5	3	1
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 7	4	7	8	2	9	13	5	10	1	11	3	12	6	14
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 8	12	11	8	14	9	10	7	1	3	6	13	5	2	4
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 9	6	7	8	2	11	4	14	12	1	13	9	3	5	10
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 10	11	1	14	5	3	6	8	2	4	7	9	13	10	12
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/

Adult 04

Block 1	12	6	3	11	9	8	7	13	2	10	5	4	14	1
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 2	11	2	1	6	7	4	10	14	12	8	5	3	9	13
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 3	9	1	7	8	3	10	6	11	4	14	5	12	2	13
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 4	1	4	5	11	8	3	2	10	7	14	13	6	12	9
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 5	4	7	11	12	14	13	8	9	1	2	5	6	3	10
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 6	11	3	1	14	4	6	7	9	10	5	13	12	8	2
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 7	3	2	14	8	7	9	6	12	5	13	1	11	10	4
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 8	13	14	10	8	11	3	7	6	4	9	2	5	12	1
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 9	12	14	2	11	8	9	10	3	7	5	4	13	1	6
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 10	1	2	9	3	14	13	8	7	10	12	5	11	4	6
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/

Adult 05

Block 1	7	13	4	6	12	5	9	1	2	10	3	11	14	8
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 2	1	4	6	5	11	14	12	10	9	3	2	13	7	8
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 3	12	1	9	7	3	2	8	6	5	14	11	13	4	10
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 4	2	6	1	13	5	14	8	12	3	11	10	7	9	4
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 5	9	14	10	11	8	13	2	6	5	1	3	4	7	12
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 6	11	3	7	14	6	9	1	10	2	8	12	5	4	13
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 7	14	6	8	2	10	4	5	3	1	9	7	12	13	11
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 8	2	12	7	9	6	4	5	10	8	14	11	1	13	3
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 9	4	6	1	11	14	10	2	12	13	9	7	5	3	8
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 10	4	6	8	7	3	1	14	5	11	9	2	13	10	12
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/

Adult 06

Block 1	6	9	11	8	12	5	10	7	4	1	3	14	2	13
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 2	11	6	10	3	4	7	12	1	9	8	14	5	13	2
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 3	5	1	8	9	14	12	13	3	4	7	6	2	10	11
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 4	11	12	1	8	3	10	2	13	5	7	14	9	4	6
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 5	2	6	14	1	5	10	14	3	7	11	13	9	4	8
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 6	11	1	12	2	13	7	14	10	9	5	4	6	3	8
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 7	8	6	5	12	14	7	11	1	2	3	4	10	9	13
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 8	11	14	8	12	13	10	5	6	4	9	7	2	3	1
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 9	3	4	6	12	1	9	5	10	14	11	2	13	7	8
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 10	11	5	10	8	3	4	6	2	1	14	13	9	7	12
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/

Adult 07

Block 1	2	13	10	11	6	4	5	3	1	14	9	8	7	12
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 2	4	10	6	1	7	9	2	12	5	3	13	11	14	8
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 3	2	4	5	10	13	11	6	12	1	3	14	7	9	8
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 4	1	13	6	12	3	2	5	9	11	4	14	10	8	7
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 5	9	10	7	1	13	4	8	6	14	5	3	11	2	12
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 6	9	1	11	13	14	7	8	10	12	2	5	3	6	4
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 7	2	5	4	8	7	6	13	10	11	1	12	14	3	9
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 8	7	1	8	10	6	3	4	13	14	2	12	11	9	5
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 9	6	13	4	9	7	5	14	3	8	2	1	11	10	12
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 10	12	6	8	10	13	1	4	2	7	11	9	5	14	3
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/

Adult 08

Block 1	2	10	14	13	7	11	1	12	4	5	3	8	6	9
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 2	13	2	3	9	4	7	1	6	10	5	11	12	8	14
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 3	5	9	3	8	11	12	14	10	2	13	6	1	7	4
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 4	1	12	5	10	6	13	2	14	4	3	9	7	8	11
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 5	1	4	8	5	9	2	7	14	10	3	13	12	6	11
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 6	12	11	4	9	1	3	14	7	2	10	13	6	8	5
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 7	7	12	4	5	1	13	11	9	10	6	3	8	14	2
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 8	5	3	8	14	9	1	6	13	10	11	4	2	7	12
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 9	3	12	11	9	7	14	5	10	1	4	6	8	13	2
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 10	8	1	7	6	2	5	3	12	14	4	11	10	9	13
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/

Adult 09

Block 1	13	3	11	2	8	4	12	6	1	7	10	14	9	5
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 2	13	8	4	3	9	1	14	5	6	10	2	11	12	7
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 3	14	1	10	13	5	8	11	4	12	9	3	6	2	7
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 4	3	11	7	2	5	4	10	8	13	6	12	1	9	14
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 5	2	1	14	3	12	9	11	13	5	8	4	6	10	7
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 6	4	1	11	6	5	13	2	12	8	3	10	14	9	7
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 7	2	11	12	8	9	13	3	14	5	7	6	1	4	10
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 8	11	8	14	13	4	3	10	7	2	1	9	5	6	12
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 9	4	12	3	11	10	2	9	14	5	1	6	7	13	8
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 10	5	1	6	13	2	12	7	10	9	3	11	14	4	8
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/

Adult 10

Block 1	5	8	1	11	3	2	4	10	12	9	13	6	7	14
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 2	14	4	6	10	8	1	13	12	7	11	2	3	5	9
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 3	1	10	6	7	4	5	14	13	12	3	2	11	9	8
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 4	7	8	14	1	10	9	6	13	5	2	11	4	3	12
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 5	6	3	2	1	9	14	10	4	8	7	13	12	5	11
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 6	9	13	14	5	4	8	12	1	11	3	6	2	7	10
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 7	14	5	13	9	12	4	3	10	11	6	1	8	7	2
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 8	12	8	1	3	11	9	10	4	13	5	7	6	2	14
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 9	13	3	1	10	9	12	11	4	2	8	7	6	14	5
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 10	5	3	11	10	14	8	1	9	6	13	4	12	7	2
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/

Older Child 01

Block 1	13	10	2	9	12	5	1	6	14	3	8	11	7	4
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 2	13	12	2	11	10	4	3	14	1	9	6	7	5	8
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 3	4	13	6	10	7	11	2	12	1	9	8	5	14	3
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 4	2	1	10	14	11	9	13	6	12	7	4	3	5	8
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 5	4	9	3	2	1	6	10	7	12	11	5	14	8	13
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 6	9	6	2	14	8	7	3	12	11	5	4	13	1	10
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 7	9	3	12	2	4	7	1	11	8	14	5	6	10	13
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 8	7	14	13	2	3	1	12	5	10	11	4	8	9	6
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 9	5	3	8	14	9	12	10	2	7	1	6	11	4	13
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 10	6	1	12	7	11	10	8	14	13	2	4	3	9	5
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/

Older Child 02

Block 1	10	1	7	12	2	8	6	9	11	4	3	5	14	13
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 2	10	1	6	8	13	9	7	4	12	3	11	14	5	2
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 3	8	10	13	7	1	9	4	3	5	14	2	6	12	11
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 4	10	5	14	4	1	9	11	2	3	8	7	6	12	13
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 5	1	6	3	12	5	13	14	10	7	11	9	4	8	2
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 6	5	6	7	1	9	8	14	11	12	13	10	3	2	4
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 7	12	13	9	8	7	11	3	1	6	2	10	4	14	5
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 8	14	1	2	10	7	13	6	12	8	3	11	9	5	4
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 9	7	12	4	5	10	2	13	8	14	3	1	9	11	6
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 10	4	6	10	2	7	13	12	9	14	5	8	11	1	3
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/

Older Child 03

Block 1	9	5	1	14	10	13	6	8	3	11	12	4	7	2
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 2	5	9	2	7	10	8	1	3	14	12	11	13	4	6
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 3	4	2	1	9	8	12	3	10	14	6	13	11	7	5
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 4	11	7	8	4	6	14	13	2	5	3	12	10	1	9
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 5	7	14	4	3	10	11	9	6	1	12	13	5	2	8
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 6	1	12	2	6	11	9	8	10	13	14	5	4	3	7
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 7	1	8	10	4	6	12	11	2	3	7	14	9	13	5
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 8	12	14	1	13	9	11	3	6	7	8	2	10	4	5
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 9	2	12	11	1	5	7	9	13	3	10	8	14	4	6
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 10	10	11	2	7	12	13	1	14	9	3	5	4	8	6
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/

Older Child 04

Block 1	6	1	3	11	2	8	12	4	9	14	7	10	5	13
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 2	13	12	3	9	10	8	7	4	14	5	11	6	1	2
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 3	4	14	5	13	1	3	6	2	11	9	7	10	12	8
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 4	14	5	8	2	11	3	10	13	12	7	6	9	4	1
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 5	8	5	7	4	2	10	14	12	1	11	3	13	6	9
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 6	7	11	4	1	13	10	2	12	5	9	14	6	3	8
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 7	7	3	11	6	5	10	14	9	8	1	2	13	12	4
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 8	1	10	8	14	3	12	5	2	4	7	11	6	9	13
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 9	12	8	11	5	1	10	9	3	7	13	6	2	14	4
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 10	8	10	5	12	6	4	13	2	7	9	1	14	3	11
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/

Older Child 05

Block 1	13	12	10	4	3	7	5	14	1	8	2	6	11	9
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 2	3	9	11	8	5	14	7	13	10	1	4	2	6	12
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 3	14	10	13	3	6	1	7	12	4	9	5	8	11	2
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 4	2	13	8	4	1	11	10	3	5	12	9	14	6	7
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 5	8	2	1	5	10	7	4	13	14	9	12	11	6	3
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 6	11	12	5	1	9	2	13	4	7	14	6	8	10	3
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 7	13	5	8	2	10	6	4	14	3	11	12	7	1	9
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 8	5	10	2	6	11	1	9	13	12	7	8	4	3	14
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 9	10	11	9	6	1	3	7	13	12	8	5	14	4	2
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 10	13	1	3	9	10	6	14	5	2	8	7	12	4	11
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/

Older Child 06

Block 1	2	3	8	10	13	11	7	1	4	12	6	5	14	9
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 2	4	1	3	10	2	12	14	13	7	11	6	5	9	8
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 3	13	4	5	3	7	12	1	10	8	11	6	9	14	2
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 4	4	12	10	8	1	11	2	13	7	3	14	5	6	9
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 5	14	9	12	7	11	6	2	1	13	8	3	5	4	10
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 6	12	14	4	8	11	2	7	5	1	3	9	10	6	13
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 7	8	7	4	6	1	10	11	13	5	14	12	2	9	3
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 8	4	14	3	5	1	2	13	12	8	11	7	6	9	10
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 9	1	10	3	11	14	4	5	2	8	13	9	6	12	7
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 10	4	12	14	3	13	11	2	9	7	5	6	10	8	1
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/

Older Child 07

Block 1	2	12	1	10	8	4	13	7	9	5	6	11	14	3
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 2	10	14	9	11	5	7	4	13	12	2	8	1	3	6
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 3	5	10	7	12	9	11	1	13	3	4	8	6	14	2
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 4	5	2	3	9	1	12	10	13	14	7	8	11	6	4
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	EE	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 5	14	8	6	10	1	5	12	2	4	3	13	9	11	7
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 6	7	6	12	14	9	8	2	3	11	5	1	4	10	13
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 7	7	10	11	13	9	4	1	3	2	5	8	14	6	12
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 8	7	11	3	4	9	6	1	2	12	8	13	14	10	5
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 9	3	4	2	6	12	8	1	14	5	9	7	11	13	10
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 10	8	2	3	14	11	4	13	6	12	5	10	7	1	9
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/

Note EE = Examiner error (examiner did not see response)

Older Child 08

Block 1	5	13	4	2	14	6	9	10	7	3	12	11	1	8
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 2	4	2	8	1	10	7	14	13	5	3	12	11	6	9
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 3	11	9	3	13	5	10	1	8	6	4	12	7	14	2
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 4	8	11	12	9	6	5	10	14	4	2	1	7	13	3
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 5	10	6	7	1	14	2	5	8	4	9	11	3	13	12
	/ɛ/	/ɛ/	NS	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 6	2	6	10	12	5	14	9	13	7	1	8	4	3	11
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 7	12	10	11	13	9	14	8	2	4	1	6	3	7	5
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 8	4	14	7	10	13	1	8	3	9	12	11	6	5	2
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 9	11	4	2	6	1	10	7	14	9	12	13	5	3	8
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 10	8	1	9	12	7	2	11	10	3	5	13	14	4	6
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/

<u>Note</u> NS = No stimulus (computer failed to present stimulus in its entirety)

Older Child 09

Block 1	12	1	10	13	11	7	8	6	3	4	9	2	5	14
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 2	10	3	14	8	1	4	12	5	11	7	2	6	13	9
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 3	4	10	6	9	3	8	12	1	2	5	11	14	13	7
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	NS	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 4	14	8	2	13	11	9	1	7	10	12	4	5	6	3
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 5	14	6	9	12	2	5	11	10	8	7	4	13	1	3
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 6	5	6	4	3	10	7	12	8	1	11	2	13	9	14
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 7	12	4	5	6	14	2	1	13	11	8	3	10	9	7
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 8	9	6	3	4	2	12	11	8	1	10	14	7	13	5
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	NS	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 9	9	8	11	4	5	14	6	13	1	12	10	3	2	7
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 10	11	13	3	10	6	5	8	4	7	2	9	12	1	14
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/

Note NS = No stimulus (computer failed to present stimulus in its entirety)

Older Child 10

Block 1	1	6	14	5	9	10	7	13	2	4	3	12	8	11
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 2	4	13	7	1	9	8	2	10	12	6	5	11	14	3
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 3	6	5	4	9	8	2	14	10	12	3	7	11	13	1
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 4	7	8	2	6	13	4	10	1	9	12	11	14	5	3
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 5	8	12	7	3	9	10	2	11	6	14	5	13	1	4
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 6	11	1	10	7	14	13	12	8	9	3	4	6	5	2
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 7	4	10	5	11	1	7	3	12	9	8	6	14	13	2
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 8	7	1	3	6	9	14	11	10	2	12	13	5	8	4
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 9	12	7	3	5	11	10	13	1	2	8	9	4	14	6
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 10	9	12	11	10	3	13	7	6	1	14	2	5	8	4
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/

Younger Child 01

Block 1	13	10	2	5	9	4	6	8	1	3	14	11	7	12
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/
Block 2	1	7	5	12	10	13	4	2	14	6	11	8	3	9
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 3	8	13	3	6	5	12	4	9	14	2	1	11	10	7
	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 4	9	6	7	10	8	1	14	12	11	2	13	4	5	3
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 5	13	5	10	3	12	14	9	6	11	8	1	7	2	4
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 6	1	6	10	4	12	11	14	8	7	9	2	13	3	5
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 7	1	3	10	12	7	2	13	4	14	11	5	9	8	6
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 8	12	4	1	14	6	9	5	11	13	3	8	7	10	2
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 9	7	1	13	8	11	3	6	10	12	9	4	2	5	14
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 10	8	4	9	1	13	14	3	5	2	6	12	11	7	10
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/

Younger Child 02

Block 1	12	10	1	13	9	8	11	6	2	4	3	5	7	14
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 2	1	12	6	3	5	8	10	11	14	2	13	9	7	4
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 3	10	11	4	14	9	12	3	13	1	2	7	6	5	8
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 4	2	13	1	8	14	6	7	10	12	11	9	5	4	3
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 5	7	13	1	9	12	6	10	2	8	3	5	14	4	11
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 6	4	3	2	10	9	12	7	8	13	6	11	5	1	14
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 7	12	13	3	1	6	8	7	10	9	4	11	5	14	2
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 8	6	10	14	3	11	8	13	12	4	5	9	7	1	2
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 9	8	12	13	1	2	7	9	10	6	3	14	5	11	4
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 10	9	14	3	12	4	6	1	8	13	10	5	2	11	7
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/

Younger Child 03

Block 1	10	6	13	12	9	11	2	1	8	3	14	5	7	4
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 2	9	8	1	12	5	10	13	7	11	14	4	2	6	3
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 3	2	3	1	5	10	11	9	7	6	8	4	14	13	12
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 4	4	7	12	1	9	8	11	6	3	10	14	2	13	5
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 5	1	10	9	3	4	11	2	13	12	8	5	6	7	14
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/
Block 6	2	14	7	12	6	5	1	3	13	10	8	9	11	4
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 7	4	1	10	3	11	12	7	2	8	9	13	14	5	6
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 8	5	2	10	12	9	4	7	14	3	11	1	13	8	6
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 9	5	12	8	4	6	11	2	7	13	14	10	9	1	3
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 10	14	1	9	5	2	12	7	6	4	10	13	3	11	8
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/

Younger Child 04

Block 1	11	8	2	9	14	4	3	13	12	6	5	1	7	10
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 2	4	5	1	2	12	11	14	3	7	10	9	13	6	8
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	NR	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 3	7	6	12	14	8	1	10	9	13	3	11	5	4	2
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 4	2	1	13	11	6	5	7	12	10	3	4	9	14	8
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 5	3	12	10	9	4	11	13	14	7	1	2	5	8	6
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 6	6	5	7	1	8	9	11	14	12	3	4	13	2	10
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 7	10	1	3	11	8	12	5	6	2	14	13	9	7	4
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/
Block 8	4	10	1	8	9	12	14	3	11	2	6	13	5	7
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 9	4	6	10	11	1	12	9	5	3	13	8	14	2	7
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/
Block 10	1	10	5	11	6	12	8	2	9	7	14	4	3	13
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/

Note NR = No response (child said she didn't hear the stimulus)

Younger Child 05

Block 1	12	4	10	2	6	8	7	13	3	14	9	5	11	1
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 2	9	2	13	14	10	3	4	12	6	7	11	1	5	8
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 3	5	9	1	11	8	4	12	6	2	13	14	7	3	10
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 4	7	3	5	2	13	10	6	12	11	9	14	4	8	1
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 5	6	10	12	13	2	1	11	14	5	3	9	4	7	8
	/ɪ/	EE	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 6	5	1	6	10	2	11	7	12	3	14	8	13	9	4
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 7	5	9	14	13	8	7	12	11	3	1	4	10	6	2
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 8	8	11	12	1	10	6	7	2	9	13	5	4	14	3
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 9	8	3	11	13	4	5	1	10	12	9	2	14	6	7
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 10	8	3	5	1	4	6	11	14	9	7	13	12	10	2
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	NS

Note EE = Examiner error (examiner didn't see response), NS = No stimulus (computer did not present stimulus in its entirity)

Younger Child 06

Block 1	3	1	10	4	8	13	11	7	14	2	6	12	9	5
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 2	13	3	11	8	5	7	14	2	6	12	4	9	10	1
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 3	5	6	7	9	1	13	3	8	2	12	4	11	14	10
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 4	3	14	12	11	5	2	8	7	10	13	1	9	4	6
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 5	6	1	11	9	13	3	2	14	4	5	7	10	12	8
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 6	6	5	11	13	12	7	10	8	1	4	9	2	3	14
	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 7	13	2	9	3	4	8	1	10	6	14	11	7	12	5
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/
Block 8	6	7	9	2	12	11	1	10	4	14	3	5	13	8
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 9	1	5	11	6	2	12	7	13	3	8	9	4	14	10
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 10	4	10	5	6	1	13	2	8	11	12	7	14	9	3
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/

Younger Child 07

Block 1	3	6	10	5	12	11	8	2	4	1	13	7	9	14
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 2	10	1	13	11	7	5	12	4	3	6	9	2	14	8
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 3	4	7	11	6	5	8	12	13	1	14	3	2	10	9
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 4	7	12	11	14	4	13	10	1	9	3	5	2	8	6
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 5	7	9	10	14	5	13	11	12	6	2	8	4	1	3
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 6	12	11	6	10	2	1	4	13	8	14	3	5	9	7
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/
Block 7	13	2	11	5	10	1	6	14	9	7	12	4	3	8
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 8	3	14	7	13	11	10	1	8	4	12	9	5	6	2
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 9	1	12	4	5	13	8	9	2	7	11	3	10	14	6
	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 10	6	12	9	10	4	5	8	2	7	3	11	13	14	1
	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/

Younger Child 08

Block 1	13	6	10	12	14	2	9	7	1	8	5	4	11	3
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 2	8	14	12	9	7	13	5	3	6	10	4	1	11	2
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 3	12	6	8	14	1	10	2	7	11	13	5	9	3	4
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 4	6	3	8	11	7	12	5	9	4	14	1	10	13	2
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/
Block 5	14	3	11	1	2	9	4	10	6	5	7	13	12	8
	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/
Block 6	8	3	1	9	7	5	11	10	13	4	2	6	14	12
	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 7	3	1	12	14	11	10	7	9	2	6	5	13	4	8
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 8	4	1	5	13	9	14	7	12	11	10	2	3	6	8
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/
Block 9	11	9	4	8	5	2	14	13	6	3	1	12	10	7
	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/
Block 10	5	8	1	11	7	13	6	14	10	9	12	3	2	4
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/

Younger Child 09

Block 1	12	10	13	14	3	8	2	7	9	5	11	6	1	4
	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/
Block 2	12	6	2	4	7	10	8	9	14	3	1	5	13	11
	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/
Block 3	4	10	12	7	5	9	11	3	1	6	2	13	14	8
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 4	10	9	13	12	3	2	6	5	4	8	11	1	7	14
	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/
Block 5	7	4	8	3	9	10	5	11	1	2	12	13	14	6
	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 6	9	8	1	14	10	11	4	3	6	2	5	12	13	7
	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 7	11	3	6	9	1	7	13	12	14	10	5	2	8	4
	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/
Block 8	3	14	12	9	2	6	4	10	1	8	13	5	11	7
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/
Block 9	1	5	2	10	13	3	4	14	8	6	9	7	12	11
	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɪ/	/ɛ/
Block 10	10	12	5	6	3	4	9	14	1	11	8	2	7	13
	/ɪ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɛ/	/ɪ/	/ɛ/	/ɪ/

Younger Child 10

Block 1	13	5	2	12	9	4	3	11	1	14	7	6	8	10
	/ε/	/ɪ/	/ɪ/	/ε/	/ε/	/ɪ/	/ɪ/	/ε/	/ɪ/	/ε/	/ɪ/	/ɪ/	/ɪ/	/ε/
Block 2	3	4	13	12	9	11	8	2	1	10	14	7	6	5
	/ɪ/	/ε/	/ε/	/ɪ/	/ε/	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ε/	/ɪ/	/ɪ/	/ε/	/ε/
Block 3	2	13	4	7	10	6	12	1	5	3	14	8	11	9
	/ɪ/	/ε/	/ɪ/	/ε/	/ε/	/ε/	/ε/	/ɪ/	/ɪ/	/ɪ/	/ε/	/ε/	/ε/	/ε/
Block 4	1	12	14	2	7	6	13	5	9	4	3	10	11	8
	/ɪ/	/ε/	/ɪ/	/ɪ/	/ε/	/ɪ/	/ε/	/ε/	/ε/	/ɪ/	/ɪ/	/ε/	/ε/	/ε/
Block 5	12	3	13	10	8	2	7	5	6	14	9	11	1	4
	/ε/	/ɪ/	/ε/	/ε/	/ε/	/ɪ/	/ε/	/ɪ/	/ɪ/	/ε/	/ε/	/ε/	/ɪ/	/ɪ/
Block 6	3	13	14	4	9	5	1	2	10	7	11	12	8	6
	/ε/	/ɪ/	/ɪ/	/ɪ/	/ε/	/ε/	/ɪ/	/ɪ/	√ε/	/ε/	/ε/	/ε/	/ɪ/	/ɪ/
Block 7	12	13	7	10	3	9	4	14	11	6	2	8	5	1
	/ε/	/ɪ/	/ɪ/	/ε/	/ɪ/	/ε/	/ɪ/	/ε/	/ɪ/	/ɪ/	/ɪ/	/ε/	/ɪ/	/ε/
Block 8	7	11	1	10	4	13	3	12	5	2	8	9	6	14
	/ε/	/ɪ/	/ɪ/	/ε/	/ɪ/	/ε/	/ε/	/ε/	/ɪ/	/ɪ/	/ɪ/	/ε/	/ɪ/	/ε/
Block 9	8	4	1	11	6	10	14	5	3	2	12	9	7	13
	/ε/	/ɪ/	/ε/	/ε/	/ε/	/ε/	/ε/	/ɪ/	/ɪ/	/ɪ/	/ε/	/ε/	/ε/	/ε/
Block 10	1	6	3	4	13	14	2	5	11	10	12	9	7	8
	/ɪ/	/ɪ/	/ɪ/	/ɪ/	/ε/	/ε/	/ɪ/	/ε/	/ε/	/ε/	/ε/	/ε/	/ε/	/ε/

VITA

Susan Pursell received her B A from the University of Tennessee in May, 1998 She graduated with summa cum laude honors She received an award for academic achievement from the Department of Audiology and Speech Pathology Currently, she is a graduate student at the University of Tennessee working toward a master's degree in speech-language pathology While at the University of Tennessee, she has gained practicum experience at the university clinic, a program for children with hearing impairments, a public school, and a nursing home

Mrs Pursell's main area of interest is language development in the preschool population She has served as program director for two preschool programs serving typically developing 3- and 4-year-old children Upon completion of her master's program, Mrs Pursell will pursue a career as a speech-language pathologist in a public school setting