To the Graduate Council:

I am submitting herewith a thesis written by Mandi Stutsy entitled "Extended High Frequency Hearing and Speech Delay of Unknown Origin." I have examined the final paper 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.

Dr. Peter Flipsen, Jr., Major Professor

We have read this thesis
and recommend its acceptance:

Dr. Jim Thelin

Mary (Molly) Er

Dr. Molly Erickson

Accepted for the Council:

Vice Provost and Dean of Graduate Studies

EXTENDED HIGH FREQUENCY HEARING AND SPEECH DELAY OF UNKNOWN ORIGIN

A Thesis Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Mandi C. Stutsy
May 2003

ACKNOWLEDGEMENTS

I would like to express my appreciation to my thesis advisor, Dr. Peter Flipsen, for his constant support and guidance throughout this process. You have been an excellent advisor and have taught me much about the research process.

In addition, I would like to thank Dr. Molly Erickson and Dr. Jim Thelin for participating on my thesis committee. I am grateful for the consistent support and interest you have shown.

Thanks to Dr. Jerry Carney for introducing me to research and supporting me throughout my thesis. I admire you greatly and appreciate the guidance and wisdom you have shown me.

I would also like to thank Jill Fussner for helping keep the children attentive during the hearing tests.

Thanks to the participants and their families for agreeing to participate in this study.

The faculty and staff personnel in the Audiology and Speech Pathology department at the University of Tennessee have been very supportive of my thesis study. I appreciate your interest in my research and the motivation you have provided me.

Further thanks goes to all of my friends, especially those in the speech pathology program. Your emotional support has helped me make it through the tedious and challenging process of thesis writing. I don't think I could have made it without your daily asking about my thesis and giving me support.

I am also appreciative to all my friends at Middlebrook Pike United Methodist Church. You have shared your lives with me and have been so supportive to me throughout the two years I have been in graduate school.

Finally, I would like to thank my parents and grandparents for being understanding and encouraging me to do my best throughout my educational career, but especially these past two years. I would not be where I am today if it weren't for you.

ABSTRACT

Objective: The purpose of the current study was to examine hearing in the extended high frequency range in children with speech delay of unknown origin. Specifically, the study asked the questions, do children with speech delay of unknown origin have reduced hearing acuity in the extended high frequencies, do children with speech delay of unknown origin and who have not acquired the high frequency sounds (/s/ and /z/) have reduced hearing acuity in the extended high frequencies, and/or do children with speech delay of unknown origin and a history of otitis media have reduced hearing acuity in the extended high frequencies?

Participants: Four children ages 3;11 to 6;8 participated in the study. The children were selected because they met the following criteria: (1) diagnosed as having speech delay of unknown origin; (2) no hearing loss in the conventional audiometric frequency range (250-4000 Hz); (3) receptive vocabulary as measured by the Peabody Picture Vocabulary Test – 3rd Edition (PPVT-III; Dunn & Dunn, 1997) within 1.3 standard deviation of the mean for their age (Standard Score 80+).

Method: Data were gathered through a case history form, an audiometer, the Goldman Fristoe Test of Articulation—2 (GFTA-2), a conversational speech sample, and the Speech Production-Perception Task (SP-PT). Hearing ability was assessed using an audiometer. These results were compared to normative values. In addition, each participant's asymmetry index was determined. To assess speech production, the GFTA-2 was given and a conversational sample was audio recorded. Percent consonants correct on the GFTA-2 and conversational speech sample were compared.

Data Analysis: Because of the small number of participants, data analysis was descriptive rather than statistical in nature. The participants' conventional hearing thresholds were compared with normative data (ANSI, 1996). The participants' extended high frequency thresholds were compared to the normative values given by Margolis (1993) and Reuter (1998). The participant's errors on the GFTA-2 and the conversational speech sample were compared and described for fricatives and other errors. The participants' performance on the SP-PT was described and compared to production of fricatives.

Results: Only participant 3 had a reduced hearing acuity in the extended high frequency range in his right ear. He also had the most severe articulation delay and a history of chronic otitis media. Participant 1 had normal hearing in the extended high frequencies, but had difficulty perceiving the difference between the phonemes /f/ and /θ/. He also had a diagnosis of ADHD. These finding suggest that for some children speech delay is associated with chronic otitis media and extended high frequency hearing loss.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TTSSD = Templin Test o f Speech Sound Discrimination
TDPAT = Templin-Darley Picture Articulation Test
EHF = Extended High Frequency
SD+OME = Speech Delay + Otitis Media with Effusion
SD+DAS = Speech Delay + Developmental Apraxia of Speech
SD+DPI = Speech Delay + Developmental psychosocial involvement
UTHSC = University of Tennessee Hearing and Speech Center
PPVT-III = Peabody Picture Vocabulary Test 3rd Edition
GFTA-2 = Goldman-Fristoe Test of Articulation 2nd Edition
GFTA = Goldman Fristoe Test of Articulation
PLS-3 = Preschool Language Scale 3rd Edition
SP-PT = Speech Production-Perception Task

CHAPTER 1

INTRODUCTION

The purpose of the current study was to examine hearing in the extended high frequency range in children with speech delay of unknown origin. Although the conventional range for audiological testing is 500 to 8000 Hz, humans are capable of hearing frequencies well above this range. However, it is not known whether the ability to hear frequencies above this range is necessary for speech. Strickland and Viemeister (1994) reported that frequencies above 8000 Hz are not necessary for speech perception in adults. In the case of fricative perception, children and adults differ in the type of information they use. Children tend to use formant transitions while adults use the spectra of noise (Nittrouer, 2002). Nittrouer reports that at some point children must transition from using formant transitions to using the acoustical spectra of noise in order to perceive fricatives. The spectra they use may be the extended high frequencies present in those sounds. In addition to helping the child perceive fricatives, this maturing perceptual trend may help the child refine his or her own productions (Nittrouer, 2002). It has been found that there is acoustic energy above 8000 Hz in some of the speech sounds children produce (Bauer & Kent, 1987; Flipsen, Shriberg, Weismer, Karlson, & McSweeny, 1999; Pentz, 1996; Pentz, Gilbert, & Zawadzki, 1979).

Specifically the question posed in the current study was whether speech delay of unknown origin is associated with reduced hearing acuity in the extended high frequency range. This reduced acuity might then at least partially account for the difficulty these children are having with learning speech.

Speech Perception

Bernthal and Bankson (1998) define phonemic perception as "a form of auditory perception in which the listener and/or speaker distinguishes the sound contrast used in a language." (p. 180) Speech language pathologists have long been interested in whether speech production disorders are caused by or in any way related to speech perception disorders. Although, it remains unclear whether there is a causal relationship between speech perception difficulties and speech production errors, several researchers have identified a significant correlation between speech sound discrimination tests and speech production errors (Perozzi & Kunze, 1971; Sherman & Geith, 1967). In addition, research has shown that there is at least a subgroup of children with speech production disorders who also have difficulties in speech perception (Eilers & Oller, 1975; Rvachew & Jamieson, 1989).

How we hear high frequency sounds

According to Stach (1998), a very sophisticated series of structures process sound in order for us to hear. The outer ear or pinna collects sound pressure waves that are then funneled to the tympanic membrane via the external auditory canal. This tympanic membrane vibrates in response to the sound, which causes a small set of cartilages in the middle ear, the ossicular chain, to be set into motion. The ossicular chain is connected to the cochlea by the round window. Movement of the ossicular chain causes the round window to move which sets the fluid of the cochlea into motion. The movement of this fluid stimulates the hair cells on the basilar membrane. These hair cells are arranged tonotopically which means that the hair cells most sensitive to low frequencies are in the apex or innermost region of the cochlea and hair cells most sensitive to high frequencies are at the base or outermost region of the cochlea. Hair cells most sensitive to these extended high frequencies (frequencies above 8000 Hz) would be closest to the outside and would be are most vulnerable to damage because of their physical location (i.e., relative nearness to the outside).

<u>The Current Study</u>

Several studies (Ahonen & McDermott, 1984; Buren, Solem, & Laukli, 1992; Harris & Ward, 1967; Margolis, Rykken, Hunter, & Giebink, 1993; Reuter, Schonfeld, Mansmann, Fischer, & Gross, 1998; Scheter, Fausti, Rappaport, & Frey, 1986; Stelmachowicz, Beauchaine, Kailberer, & Jesteadt, 1989) have examined extended high frequency hearing in children. To date, there have been no studies looking at the hearing acuity in the extended high frequency range for children with speech delay of unknown origin. Many children in this population have difficulty producing sounds containing high frequency energy. Extended high frequency hearing may be relevant because several studies (Bauer & Kent, 1987; Flipsen, et al., 1999; Pentz, 1996; Pentz et al., 1979) have shown that there is acoustic energy in children's production of fricatives above 8000 Hz. An increased risk of speech delay has been associated with a history of otitis media (Shriberg, Flipsen, Thiekle, Kwiatkowski, Kertoy, Nellis, and Block, 2000). A number of studies (Ahonen & McDermott, 1984; Hunter, Margolis, Rykken, Le, Daly, & Giebink, 1996; Laitila, Karma, Sipila, Manninen, & Rahko, 1997; Lopponen, Sorri, Pekkala, & Penna, 1992; Margolis et al., 1993; Margolis, Saly, & Hunter, 2000; McDermott, Fausti, & Frey, 1986) have examined extended high frequency hearing in children with chronic otits media. These studies revealed that children with a history of otitis media have decreased hearing acuity in this range.

Research Questions

1. Do children with speech delay of unknown origin have reduced hearing acuity in the extended high frequencies?
2. Do children with speech delay of unknown origin and who have not acquired the high frequency sounds (/s/ and /z/) have reduced hearing acuity in the extended high frequencies?
3. Do children with speech delay of unknown origin and a history of otitis media have reduced hearing acuity in the extended high frequencies?

CHAPTER 2

REVIEW OF LITERATURE

Speech Perception

Research has shown that there is a subgroup of children with speech production disorders who also have speech perception difficulties (Eilers & Oller, 1975; Rvachew & Jamieson, 1989). It remains unclear whether the perception difficulties are a causal factor in speech production errors even for this subgroup. However, several researchers have identified a significant correlation between speech sound discrimination tests and speech production errors (Perozzi & Kunze, 1971; Sherman & Geith, 1967).

According to Locke (1980a), even if it were determined that a child misperceives speech in the same manner as he mispronounces it, it would still be unknown if the child's production errors were motivated or maintained by problems of perception. Allison (1975) reports, "Children with defective articulation are typically unaware that their speech is considered defective or different by listeners" (p. 349). Locke (1980a) proposed that the only good indicator of the organization of a child's receptive phonology is a procedure that infers the child's perception. This assessment would not only provide a more complete understanding of the child's phonological system, but would also clarify the extent to which the problem is with linguistic rules or with production or perception inadequacies.

Speech perception has been assessed in a number of ways over the years. Some tests of speech-sound discrimination test all speech sounds, not just the specific sounds that a child misarticulates. These are considered "general" tests of discrimination. Research by Eilers and Oller (1975) using a general test of speech sound discrimination concluded that perceptual confusions are likely to play a role in childhood speech errors, but not all errors are related to perception problems. Sherman and Geith (1967) also used a general discrimination test, the Templin Test of Speech Sound Discrimination (TTSSD, Templin, 1957) to determine the relationship between articulation and speech sound discrimination. They found that children scoring high on the test of speech sound discrimination also scored high on the Templin-Darley Picture Articulation Test (TDPAT, Templin & Darley, 1960). In addition, children scoring low on the speech sound discrimination test also scored low on the articulation test. This supports a possible relationship between discrimination abilities and production abilities.

General speech sound discrimination tests do not all measure comparable skills. They vary in terms of number of stimulus items, types of contrasts tested, meaningfulness of stimuli and manner of stimuli presentation. Because of this variability, some researchers recommend evaluating perception based on specific error sounds produced rather than sounds that may be irrelevant to their errors (Lof & Synan, 1997). Locke (1980a) presented eight criteria that make a test of speech perception useful and valid clinically. He stated that it would be of no clinical relevance to sample all major contrasts or to test every sound because the child does not misproduce all sounds. The assessment of perception should only test the sounds the child misproduces. The misproduced sounds should be tested in relation to the sounds the child substitutes. For example, if the child substitutes /t/ for /k/, it would be inappropriate to test a /k/-/g/ contrast. Therefore, Locke's first criterion is that the assessment should test the perception of mispronounced sounds in relation to the sound substituted.

Locke's (1980a) second criteria is the task must observe the same phonemes in identical phonetic environments in production and perception. Hoffman, Daniloff, Bengoa, and Schuckers (1985) used a specific discrimination test of /r/ and /w/. These researchers found that although children who misarticulated /r/ were readily able to identify /r/ versus /w/ when presented via live voice, they had more difficulty with this task when presented with synthetic stimuli. It is suggested that in normal conversation, children who misarticulate /r/ may use cues other than formant trajectories, such as degree of lip rounding, to distinguish /r/ and /w/. Rvachew and Jamieson (1989) also used a specific test of discrimination of the sounds /s/ and /ʃ/. Subjects in this study were required to identify synthetic versions of the words 'seat' and 'sheet' only on the basis of spectral characteristics of the fricative portions of stimuli. They determined that children with functional articulation disorders (i.e., speech delay of unknown origin) form at least two subgroups: those with and those without speech perception difficulties.

In addition, Locke's (1980a) third criterion suggests that the test must permit a comparison of the child's discrimination of the target sound and replaced sound, with the discrimination of the target sound, and a perceptually similar control sound. This ensures that the child understands the instructions and is attending to the task on each sound. Locke (1980b) developed the Speech Production-Perception Task (SP-PT) because the available tests at the time didn't satisfy his criteria. In Locke's task, children are first asked to name pictures (e.g. *thumb*). For the phonemes, that are misarticulated, a series of questions are asked in which the same labels are articulated correctly (*thumb*), incorrectly with the child's usual error (*sum*), and with in a neutral but incorrect way (*fum*). The neutral phoneme should be perceptually similar to both the target and the error sound and it should be in the child's phonetic inventory. McGregor and Schwartz (1992) used the SP-PT to examine the source of a single child's production errors. Because the subject's perceptual ability was not greater than or equivalent to his articulatory ability of a given target/error pair, the authors concluded that the subject's errors could be due to "limited underlying perceptual knowledge and/or limited underlying articulatory knowledge" (p 601).

Another factor to take into consideration is whether a test requires the child to compare two adult forms or the adult form and the child's internal representation of the sound. This is Locke's fourth criterion (Locke, 1980a). Bernthal and Bankson (1998), describe these two types of tests as tests of external discrimination and tests of internal discrimination. External discrimination is defined as a task that involves discriminating stimuli presented from an external source, such as another person or recording. A true test of internal discrimination would involve judgment of one's own live ongoing speech sound productions. However, there doesn't seem to be a way to measure internal discrimination.

Sherman and Geith (1967) used the TTSSD, an external discrimination test, to compare speech sound discrimination and articulation skill. This test consists of 50 pairs of nonsense syllables, each of which includes either two identical items or two items differing by one phoneme. The subject is required to judge whether the syllables are the same or different. Sherman and Geith then divided children into a "high speech sound discrimination group" and a "low speech sound discrimination group" based on their scores on the TTSSD. These scores were then compared to the subjects' scores on the TDPAT. The results of this study indicated that children scoring low on the TTSSD also scored low on the TDPAT, and children scoring high on the TTSSD also scored high on the TDPAT.

Locke (1980a) suggested that in order to be clinically effective, the task must be based on a comparison of the adult surface form and the child's internal representation. This allows the clinician to determine whether the sound the client hears differs from the way the child has it stored in his storage of sounds heard. Velleman (1988) used this kind of task to describe the role of linguistic perception in later phonologic development. Children were required to point to the picture of "some," "Fum," or "thumb" as said by the examiner. The results of this study indicated that perception and production of /θ/ are highly correlated and children who discriminate /θ/well perform better on /θ/ production tasks than those who do not discriminate /θ/ well. However, this correlation was not found for the /s/ phoneme.

Locke (1980a) acknowledged that all children, including normal speaking children will miss some items on a test, due to internal noise and distractibility. Therefore, Locke's fifth and sixth criterion state that tests of speech perception must present several repeated opportunities for the child to respond and must prevent nonperceptual errors from masquerading as perceptual errors. In order to do this, Locke suggested that multiple trials be provided for every item so that a quantitative analysis may be performed rather than assigning a score by counting errors. In addition, the test should be fairly short and require a response that is easily within the child's conceptual ability. This is Locke's seventh criterion for speech production tests.

Compton (1970) pointed out that if a substitution were purely perceptual, the child would think the substituted phoneme could represent the targeted phoneme, but not the reverse. For example, if a child substituted /w/ for /ɾ/, he may think that /ɾ/ could be correct by saying /w/ or /ɾ/, but /w/ was only correct by saying /w/. Therefore, Locke's (1980a) final criterion for a good perceptual assessment is that the task should allow a determination of the direction of the misperception.

Locke (1980a) reviewed a number of speech discrimination tests and found no tests that met the above criteria. Therefore, Locke (1980b) developed the SP-PT to meet the eight criteria.

Extended High Frequency Hearing

Conventional audiometry includes frequencies from 250 to 8000 Hz, a range accepted based on early speech perception research and ease of administration (Fausti, Erickson, Frey, Rappaport, & Schechter, 1981). Extended high frequency (EHF) audiometry measures hearing in the frequencies from 8000 to 20,000 Hz. Research suggests that damage to the cochlea due to noise, otitis media, or ototoxins can be seen using EHF audiometry earlier than the use of conventional audiometry (Dreschler, Hulst, Tange, & Urbanus, 1985; Fausti et al., 1981; Laitila et al., 1997; Margolis et al., 1993; Margolis et al., 2000).

Measurement Issues

Research on EHF has had to address a number of technical problems including obtaining sufficiently high sound pressure levels, positioning of the acoustic source in relation to the ear canal, and selecting standardized procedures (Reuter, et al., 1998). According to Stevens, Berkovitz, Kidd, and Green (1987), "Measurement of the absolute threshold of hearing at high frequencies is beset by the problem of how to deliver sound to the human ear canal, how to determine the location in the ear at which to specify the stimulus, and how to measure the magnitude of the stimulus." (p. 470) The equipment used to measure EHF thresholds has varied among researchers, as until recently there was no standard audiometer or method of testing.

Early on, special equipment was devised to study EHF hearing (Vasallo, Sataloff, & Menduke, 1968). High frequency signals were generated using a condenser microphone (Vasallo et al.), by filtering the output of a white noise generator (Trehub, Schneider, Morrongiello, & Thorpe, 1989), or by filtering the output of a high-frequency transducer (Stevens et al., 1987). Special measurement techniques including direct measurement of sound pressure near the tympanic membrane with a small microphone and various models of calibration have been used to overcome problems with the varying sound pressure due to small wavelengths and standing waves in the ear canal (Fausti, Frey, Erickson, Rappaport, Cleary, & Brummet, 1979; Stelmachowicz, Gorga, & Cullen, 1982; Stevens et al., 1987). These problems have been dealt with by using insert earphones or by using Koss HV/IA earphones (Ahonen & McDermott, 1984; Buren et al, 1992; Scheter et al., 1986, McDermott et al., 1986; Stelmachowicz et al., 1986; Zislis & Fletcher, 1966).

EHF Norms

Early studies of EHF hearing have focused on adult subjects. Recent literature has attempted to establish norms for children and adolescents (Ahonen & McDermott, 1984; Buren et al., 1992; Harris & Ward, 1967; Margolis et al., 1993; McDermott et al., 1984; Reuter et al., 1998; Scheter et al., 1986; Stelmachowicz et al., 1989). Some of these studies found a marked age-dependant change in EHF thresholds with 10-16 year olds having the lowest thresholds (Stelmachowicz, 1989; Trehub et al., 1989). Two studies (Margolis et al., 1993; Reuter et al., 1998) have established normative values for children the same age as the present study (i.e., 3 years to 7 years old). These values are shown in Table 1. The mean thresholds (in decibels) for each frequency (in kHz) from these two studies are shown in Table 1.

Extended High Frequency Hearing and Otitis Media

It has been reported that there is an increased risk of speech delay associated with a history of otitis media (Shriberg et al., 2000). Several studies have reported the presence of hearing loss in the extended high frequencies in children with histories of acute and secretory otitis media (Ahonen & McDermott, 1984; Hunter et al., 1996; Laitila et al., 1997; Lopponen et al., 1992; Margolis et al., 1993; Margolis et al., 2000; McDermott, et al., 1986). Margolis, et al. (2000) divided subjects with otitis media into "Better Hearing" and "Worse Hearing" groups based on their average hearing thresholds in the 9 to 16 kHz range. They found that the Worse Hearing group had slightly poorer thresholds in the conventional audiometric range and there was a significant difference

Table 1. Normative EHF Values (dB SPL)

	8	10	11.2	12	12.5	13	14	16
Reuter et al. (1998)	28.2	26.6	31.5	35.7		35.3	41.7	41
Margolis et al. (1993)		22	28		32		35	42

between the Worse Hearing group and the other two groups in the EHF range.

The nature of the EHF hearing loss, whether conductive or sensorineural still remains unclear (Laitila, et al., 1997). It has been suggested that the passing of ototoxins from otitis media through the semipermeable round window may have caused damage at the base of the cochlea (Hunter, et al., 1996; Margolis, et al., 1993). Some studies (Hunter, et al., 1996; Margolis et al., 2000) have suggested that the EHF hearing loss in patients with otitis media is cochlear in origin. The strong frequency dependence with increasing hearing loss at high frequencies is consistent with a mechanism of transmission of otitis media related toxins through the round window membrane. There was also no relationship between tympanometric findings and conventional or EHF thresholds which further supports the likelihood that the hearing loss in patients with otitis media is cochlear in origin.

Several studies (Hunter, et al., 1996; Margolis, et al., 1993) have examined the possible effects of residual middle ear dysfunction by studying the relationship of multifrequency tympanometry and high frequency hearing. Margolis, et al. (1993) separated the otitis media group based on tympanometric results. The groups were classified based on normal or abnormal 226-Hz admittance magnitude tympanograms and multifrequency tympanograms. The normal group was found to be significantly different from all the other groups. There was a trend for those with abnormal 226-Hz tympanograms to have poorer hearing than those with normal 226-Hz tympanograms. However, this did not reach statistical significance. Hunter et al. (2000) divided the groups based on the same tympanogram criteria and the presence or absence of active otitis media. They found no significant differences in the control group and otitis media groups that had normal 226-Hz tympanograms. The group with abnormal 226-Hz tympanograms had slightly poorer hearing than the control group. This difference was statistically significant. The active otitis media group had poorer hearing than the groups with normal 226-Hz tympanograms, but was not significantly different from the group with abnormal 226-Hz tympanograms, which had residual mechanical dysfunction. Hunter et al. (2000) reported a "significant interaction between frequency and group, indicating that the effect of otitis media on high frequency hearing changed as a function of frequency." (p. 6) The differences increased as frequency increased.

Margolis et al. (2000) measured wideband impedance and reflectance of the middle ear in order to determine the relationship between middle ear impedance and EHF hearing in children with otitis media histories. They found that the Worse Hearing group had slightly lower acoustic resistance that the other two groups in the low-frequency range, but not in the high frequency range. The absence of a relationship between EHF hearing and impedance/reflectance characteristics serves as further evidence that the high-frequency hearing losses observed in children with histories of otitis media are cochlear in origin.

Speech and Extended High Frequency Hearing

Several studies show that there is spectral information above 8000 Hz in children's productions of fricatives (Bauer & Kent, 1987; Flipsen et al., 1999; Pentz, 1996; Pentz et al., 1979). Pentz et al. (1979) reports mean resonance values above 8000 Hz for four fricatives of children ages 8 to 11 years. These fricatives and their resonance values were as follows: /v/--11.4 kHz, /f/--11.2 kHz, /s/--8.4 kHz, /z/--8.3 kHz. Pentz (1999) reports mean frequencies of /s/ across vowel and word position as 8114 Hz for 7 year old children, 8118 Hz for 9 year old children and 8216 Hz for 11 year old children. Flipsen et al. (1996) found the frequencies of /s/ in 9 to 11 year old females to reach the upper limits of the analysis band used in their study (9.8 kHz). Finally, Bauer and Kent, (1987) found fricatives of infants to range in frequencies from 2.6 to 14.0 kHz. The resonant frequency values are higher than those values of adult male and female speakers

(Pentz et al., 1979). This difference can be attributed to the fact that children have smaller vocal tracts than adults (Bauer & Kent, 1987; Pentz et al., 1979).

Speech Discrimination and Extended High Frequency Hearing

Strickland and Viemeister (1994) determined that fibers with characteristic frequencies above 8000 Hz were not necessary for speech perception in adults. The authors determined the contribution of high characteristic frequency fibers to speech perception by measuring speech recognition with and without the presence of high-frequency noise intended to mask the information in these fibers while leaving the information in the fibers containing characteristic frequencies for speech intact. There was no significant difference in performance. However, some listeners were able to identify the words "toothbrush" and "grandson" without the high pass noise, but could not recognize them when the high pass noise was added. This suggests that these subjects were using the presence of the /s/ and /ʃ/ to identify these words and the addition of the high-pass noise made these sounds inaudible. This then suggests that some listeners may require information from high frequencies for speech recognition. This study was performed on adults only. It is not clear if children require information from fibers of high frequencies for speech perception. According to Bauer and Kent (1979), infants' hearing in higher frequency ranges must be considered when assessing the infant's ability to match the sounds of adults. Bauer and Kent point out that these ranges have a greater role in infant's auditory self-stimulation than adult's self-stimulation. In addition, any hearing loss in the high-frequency range could limit the role of auditory feedback in phonetic development.

Nittrouer (2002) discussed the developmental changes in the informational aspects of the signal that one attended to as children gain experience listening to and speaking a certain language. One experiment traced the developmental shift of the perception of the /s/-vowel and /ʃ/-vowel syllables. This experiment found a developmental shift in the relative amount of attention children between the ages of 3 ½ and 7 ½ paid to the acoustic properties. Adult speakers paid more attention to the spectrum of noise whereas young children paid more attention to formant transitions (Nittrouer & Miller, 1997). In an experiment that examined developmental changes in perception of /f/ and /θ/, both adults and children paid attention to formant transitions more than the fricative-noise spectra. However, 8-year-olds paid more attention to the fricative-noise spectra than the other groups. The authors suggest that this was a case of overgeneralization or looking at acoustic detail for clues to phonetic structure. According to Nittrouer (2002), "as children gain experience with their native language, it is proposed, perceptual attention (i.e. weight) gradually shifts to take advantage of the properties of the acoustic signal that are most informative regarding phonetic structure." (p. 718) In addition to helping the child access the phonetic structure of the message, this maturing perceptual trend helps the child refine his or her own productions (Nittrouer, 2002).

Speech Delay of Unknown Origin

Shriberg (1994) proposes five subtypes of developmental phonological disorders: speech delay, speech delay + otitis media with effusion, speech delay + developmental apraxia of speech, speech delay + developmental psychosocial involvement, and residual errors. Shriberg (1994) describes children with speech delay of unknown origin as having "an intelligibility problem that includes deletion and substitution errors that are not appropriate for the child's age" (p. 42). In addition, this intelligibility problem is not associated with a clinical entity including hearing loss, craniofacial dysmorphology or dysfunction, cognitive disability, or emotional disturbance. Shriberg's categories are only proposals and thus for any one child, the cause is unknown. In addition four of his five categories are labeled "speech delay." This term is preferred for the current study over "phonological disorders" because it is neutral regarding the nature of the errors (i.e., articulatory or phonological).

The first category described by Shriberg (1994) is speech delay with no other speech mechanism or psychological involvement. Shriberg suggests that these disorders may be associated with familial aggregation. The origins may be found in a common gene. Shriberg reported that up to 60% of children who fall into this category have one or more family members who have had a speech disorder.

Looking at Shriberg's (1994) categories, children with speech delay + otitis media with effusion (SD+OME) must meet the criteria for speech delay plus have at least six episodes of recurrent otitis media with effusion in the first three years of life. These children often have additional evidence of fluctuating hearing loss. Shriberg estimated this group comprises about 30% of children with intelligibility problems of unknown origin.

The third subtype of phonological disorders of unknown origin described by Shriberg (1994) is speech delay associated with developmental apraxia of speech (SD+DAS). These children have intelligibility errors including deletions and substitutions not appropriate for their age and "have problems selecting and sequencing speech sounds and different prosody patterns" (p. 47).

Shriberg's (1994) fourth subtype of phonological disorders of unknown origin is speech delay associated with developmental psychosocial involvement (SD+DPI). These children's speech delays seem to be connected to and maintain by developmental psychosocial involvements. These children are identified using information taken from case history information, social work, follow up information, and exceptional education services the child is receiving.

The final subtype Shriberg (1994) described is residual errors. These children retain at least one articulation error that is questionable at 6 years of age and continues past 9 years of age. There are children with residual errors who have qualified as speech delay earlier in their lives as well as children with residual errors who have do not meet this criteria earlier. The most common residual errors are the distortions of sibilant fricative /s/and liquid consonants /l/ and /r/.

CHAPTER 3

METHOD

Participants

Children who were currently receiving therapy at the University of Tennessee Hearing and Speech Center (UTHSC) participated in this study. The children were chosen based on the following criteria: (1) diagnosed as having an speech delay of unknown origin; (2) no hearing loss in the conventional audiometric frequency range (250-4000 Hz); (3) receptive vocabulary as measured by the Peabody Picture Vocabulary Test – 3rd Edition (PPVT-III; Dunn & Dunn, 1997) within 1.3 standard deviation of the mean for their age (Standard Score 80+).

The clinic coordinator at UTHSC was contacted in order to identify potential participants. Each child's individual supervisor was then consulted to insure they met the study criteria. After talking to the supervisor, the researcher met with the parents to discuss the study and obtain written informed consent (see Appendix).

Seven children were recruited. Three children withdrew from the study prior to testing, two because of scheduling conflicts and one withdrew consent because the family withdrew the child from therapy at UTHSC. One child refused to participate in the second day of testing. Data for day 1 for this child (participant 4) was retained with permission of the parent. The four children are described in the Table 2.

All four children who participated were males between 3;11 and 6;10 years of age. They were all originally identified as having speech delay between the ages 3;5 and 4;0.

Participant 1 had a higher percentile rank on his original Goldman-Fristoe Test of Articulation – 2 (GFTA-2; Goldman & Fristoe, 2001) than the other 3 participants, which indicates that his speech delay was not as severe when originally identified. Participant 3 had the lowest percentile rank on his current GFTA-2, indicating that his speech delay

Table 2. Participant Data

	Participant 1	Participant 2	Participant 3	Participant 4
Current age	5;6	6;8	5;10	3;11
Age at diagnosis	4;1	3;11	4;0	3;5
Time in Therapy	1 year	2 years; 9 months	9 months	
Original GFTA percentile rank	5%	<1%*	<1%*	<1%*
Current GFTA-2 percentile rank	21%	27%	11%	****
Current Severity in Connected Speech**	Mild to moderate (81%)	Mild (89%)	Mild (87%)	****
Otitis Media History	yes	No	Yes, recurring several times a year	No
Tympanostomy tubes?	Yes at age 2	No	Yes, prior to age 4;6, then again at age 5;9	No
Tonsils and adenoids removed?	No	Yes, at age 4;8, resulting in hypernasality	Yes, at age 5;9	No
Babble	1 year	1 year	9 months	unknown
Single Words	2 year	2 year	18 months	2 years
2-3 word utterances	3 year	3 year	2 years	2 ½ years
PPVT-III score	91	103	122	76***
Other	* Prenatal brain swelling * diagnosis of ADHD	Surgery to remove vocal fold nodules at age 6;6.		Participant presented with negative pressure in middle ear.

* percentile on original version of GFTA (Goldman & Fristoe, 1986)
** determined from percent consonants correct (shown in parenthesis)
*** Likely not a true representative of participant's ability (see text).

had not improved as much as participants 1 and 2 with therapy, although he has been in therapy longer. No current GFTA-2 data were available for participant 4.

Both participants 1 and 3 had a history of otitis media which had been treated with tympanostomy tubes. Participants 2 and 4 reported no history of otitis media. Participant 3 was reported to have a history of allergies accompanied by ear and sinus infections that occur several times a year. He had two episodes of otitis media within the year prior to his diagnostic evaluation at age 4;0. Participant 3 had a second set of tympanostomy tubes inserted in December of 2002. No details were available on the frequency of otitis media in participant 1.

Both participants 2 and 3 have had their tonsils and adenoids removed. Participant 2 did not report history of otitis media, however the removal of his tonsils and adenoids may indicate an undiagnosed or unreported history of otitis media. For participant 2, this removal led to hypernasality which was observed in his conversational speech during current testing. This did not appear to significantly impact the intelligibility of his speech.

As shown in Table 2, all of the children developed speech milestones of babbling, first words, and two to three word utterances later than would be expected of typically developing children. These milestones are expected to develop at 4 months, 12 months, and 18 months respectively (Owens, 1996).

The PPVT-III was administered to measure each participant's receptive vocabulary. Participants 1-3 scored within the normal range. Participant 4 had a standard score of 76. Although this score is below the inclusionary criterion for the current study, he was included in this study because it was believed that his performance on the PPVT-III did not represent his current ability. During testing he appeared fatigued and responded very quickly to many items. Both his mother and supervisor suggested his performance would otherwise have been in the normal range. In addition, the auditory reception portion of the Preschool Language Scale – 3rd Edition (PLS-3; Zimmerman, Steiner, & Pond, 1993) had been administered in April 2002, and he achieved a standard score of 106.

Other case history facts of note were that participant 1 was reported as having prenatal brain swelling which was resolved by birth, and participant 2 had vocal nodules removed at the age of 6;6. In addition, participant 1 had a diagnosis of attention hyperactivity deficit disorder and was on medication to increase attention.

Test Protocol

The following procedures were used to gather data for the current study: (1) tympanometry; (2) a conventional hearing threshold test; (3) extended high frequency thresholds; (4) the PPVT-III; (5) the GFTA-2; (6) conversational speech sample; (7) the Speech Perception-Production Test (SP-PT; Locke, 1980b) for the speech sounds /s, ʃ, f, θ/; and (8) an oral facial exam. On day 1, tympanometry, conventional hearing thresholds, extended high frequency thresholds, and the PPVT- III were performed. The conventional hearing thresholds and extended high frequency thresholds were obtained in a double-wall sound treated booth. The PPVT-III was given in a single-wall sound treated booth. On day 2, the GFTA-2, conversational speech sample, the SP-PT for the speech sounds /s, ʃ, f, θ/, and the oral facial exam were performed in a single-wall sound treated booth.

Middle Ear Functioning Screening (Tympanometry)

Tympanograms were obtained using a tympanometer (GSI-37 Auto Tymp) with a probe frequency of 226 Hz. This is a widely-used procedure intended to look at the mobility of the tympanic membrane (eardrum) and the middle ear ossicles (cartilages). It is a procedure routinely carried out by audiologists and by physicians on young children as an indirect measure of whether there is fluid in the middle ear space. The presence of such fluid would be an indicator that hearing had been affected by a transient middle ear problem and thus would necessitate rescheduling for any child who failed this test.

Tympanograms are classified into three types: Types A, B, and C. A normal tympanogram is labeled Type A. Type B tympanograms have a flat shape and are usually indicative of a fluid-filled middle ear. They would also be consistent with the presence of patent tympanostomy tubes. Type C tympanograms are consistent with negative pressure in the middle ear. Participant 3 had type B tympanograms. As shown in Table 2, this participant had recently had tympanostomy tubes inserted. Participant 4 had type C tympanograms.

<u>Conventional Hearing Threshold Test</u>

Conventional hearing thresholds were obtained at the following frequencies: 500, 1000, 2000, and 4000 Hz. Thresholds were obtained using a diagnostic audiometer (Madsen, Orbiter 922 Version 2) with circumaural earphones (Telephonics, TDH-39) earphones. Testing was conducted in a double-wall sound-treated booth.

<u>Extended High Frequency Hearing Thresholds</u>

Hearing acuity in the extended high frequency range was assessed by determining the threshold of hearing at the frequencies 8000, 10,000, 11,200, and 14000 Hz. Testing was conducted using the same audiometer as the conventional testing except that EHF earphones (Sennheiser, HAD 200) earphones were used. Initially sounds were presented at approximately 30 dB HL and then made progressively softer. As with the conventional hearing screening, testing was conducted in a double-wall sound-treated booth. To obtain these thresholds, it was necessary to take breaks to ensure the child was attentive and able to respond.

<u>Peabody Picture Vocabulary Test III</u>

This is a norm-referenced test which examines the ability of an individual to recognize the names of common objects and actions. This test was included to ensure that participants had sufficient receptive language skills to understand the other tasks. For each item on the test, the child was shown a display of four pictures (black and white drawings) and the examiner named one of the pictures. The child's task was to point to the picture they thought corresponded to what they heard. The test took 10-15 minutes to complete. Criteria for basal and ceiling scores are provided by the test developers. Based on the number of items correctly identified, various types of standard scores (e.g., percentile ranks, Weschler-type standard scores) were generated using the normative tables provided. For purposes of this study, Weschler-type standard scores (which have a mean of 100 and standard deviation of 15) were used.

Goldman-Fristoe Test Of Articulation - 2

This is a standardized test of speech sound production. The child was shown a series of pictures and asked to name each one in turn. This task was audio recorded. On-line transcriptions of productions were confirmed from the recordings. Based on the number of items correctly identified, percentile ranks were generated and used for a subsequent analyses. Comparison of results from this test with the later phonetic analysis of the conversational speech samples also allowed for the comparison of performance across the two tasks (single words vs. connected speech).

Conversational Speech Sample

This task involved the examiner making an audiotape recording while having a conversation with the child for 10-15 minutes. The target length for the sample was 90 different words. Samples of this length have been shown to provide a representative sample of English phones and syllable shapes (Shriberg, 1986). If the child achieved this target before 10 minutes, the sample was continued to get at least 10 minutes of speech. If the child had not produced 90 different words after 15 minutes, the sample was to be terminated to avoid fatigue. Participants 1-3 had 104, 112, and 109 different words in their samples respectively. The children were presented with a magnetic scene of a town. They were instructed to place the magnetic characters on the town and tell the clinician about what was going on in the town. Participant 2 grew tired of the activity and then described a page from Richard Scarry's Busiest People Ever book. The recorded sample was transcribed phonetically to evaluate the accuracy of speech sound production (Shriberg & Kent, 1995). Results obtained were compared to those obtained on the GFTA – 2. This task was included because some research has shown that single word tasks and connected speech do not necessarily yield the same results (e.g., DuBois & Bernthal, 1978; Morrison & Shriberg, 1992).

Speech Production-Perception Test (SP-PT)

This is an informal instrument designed by Locke (1980b) to look at the relationship between a child's production errors and their ability to perceive the difference between a child's production errors and the target sound. Specifically, it tests the child's errors and correct sound. It is a listening test. The examiner creates an individual test for each of the child's production errors using the intended sound (target), the sound being used in its place (error) and a third sound that is similar to both the target and the error (control). The child listens while the examiner says the target word one of three ways: with the correct sound, with the error sound, or with the control sound. For each word, the child has to decide if the word was produced correctly. The child will fail a sound if he misperceives the correct sound three or more times. In the current study, the task was modified so that only four target sounds were examined: /s, ʃ, f, θ/. Because few of the children in the current study produced these sounds in error on the GFTA-2, a general test focusing on these four sounds was given to all children. The test therefore became whether they could hear the difference among these four fricatives. For each of the four target sounds, one of the remaining three sounds was used as the error phoneme while another was used as the control phoneme. These four sounds are particularly relevant for the current study because they all include considerable sound energy in the EHF range (Bauer & Kent, 1987; Flipsen et al., 1999; Pentz, 1996; Pentz et al., 1979;).

Oral Facial Exam

This examination is intended to determine whether structure and basic functioning of the speech mechanism is adequate for producing normal speech. The examiner used a checklist to look for obvious abnormalities (see Appendix).

Data Analysis

Because of the small number of participants, data analysis was descriptive rather than statistical in nature.

The participants' conventional hearing thresholds were compared with normative data (ANSI, 1996). Each participant's puretone thresholds were averaged in each ear. An average puretone threshold was computed for each ear and also the difference between average thresholds was computed as an index of asymmetry between the ears.

Margolis et al. (1993) and Reuter et al. (1998) presented their normative data in dB SPL. These data were converted to dB HL by subtracting the reference equivalent threshold sound pressure level (ANSI, 1996, Table C1) from the value given for each frequency. The participants' EHF thresholds were averaged and compared to these values. The participant's asymmetry index was determined for EHF in the same manner as for conventional hearing frequencies.

The participant's errors on the GFTA—2 and the conversational speech sample were compared and described for fricatives and other errors. Their performance on singleton fricatives was compared with their performance on clusters containing fricatives. The participants' performance on voiceless fricatives was compared with their voiced cognates.

The participants' performance on the SP-PT was described and compared to production of fricatives. A general SP-PT focusing on the high frequency sounds /s , ʃ , f , θ/ was given to the children. The percentage of errors on each fricative contrast

(/f/ versus /θ/, /f/ versus /s/, /θ/ versus /s/, /s/ versus /ʃ/, and /ʃ/ versus /θ/) was calculated. A child failed the perception test for a particular contrast if they misperceived 50% of the contrast.

CHAPTER 4

RESULTS

Conventional Hearing

Conventional hearing thresholds for the participants are shown in Table 3. In addition, the average threshold for the group is shown in Figure 1. All participants performed within normal limits on the conventional hearing test. Participants 1-4 had asymmetry indices of 2.5 dB, 1.25 dB, 1.25 dB and 5 dB respectively.

Extended High Frequency Hearing

EHF hearing thresholds are also shown in Table 3. The average EHF threshold for the group is also shown in Chart 1 along with normative values from Margolis et al. (1993) and Reuter et al. (1998). Participants 1, 2, and 4 performed within normal limits on the extended high frequency thresholds.

Participant 3 performed within normal limits on his left ear, but had difficulties in the right ear with the frequencies 10,000 and 11,200 Hz. Recall that Participant 3 had the most extensive and most severe history of otitis media (see Table 2). In addition, he had more errors producing fricatives (see below). Participants 1-4 had asymmetry indices of 5 dB, 1.25 dB, 15 dB, and 2.5 dB respectively.

Speech Production

The participants' speech errors are reported in Tables 4-6. All participants had errors on more sounds in conversation than in single words. Participants 1-3 had errors on 10, 5, and 16 sounds respectively in single words. The three participants had errors on 17, 17, and 20 sounds in conversation respectively. This is consistent with previous studies (DuBois & Bernthal, 1978, Morrison & Shriberg, 1992). However, the participants did not all have more consonants correct on single words than in conversation. Participant 1 had the same percentage of consonants correct in single words as in conversation (81%).

Table 3. Participant Hearing Thresholds (dB HL)								
	Participant 1		Participant 2		Participant 3		Participant 4	
	Left	Right	Left	Right	Left	Right	Left	Right
500	0	-5	10	15	5	10	10	10
1000	0	0	15	15	5	10	10	10
2000	0	5	10	5	10	5	10	0
4000	-5	5	5	0	10	0	20	10
Average	-1.25	1.25	10	8.75	7.5	6.25	12.5	7.5
8000	-5	10	5	-5	0	5	5	0
10000	-5	-5	0	5	0	25	5	10
11200	-5	0	10	10	5	25	5	15
14000	-10	-10	-10	-10	0	10	10	10
Average	-6.25	-1.25	1.25	0	1.25	16.25	6.25	8.75

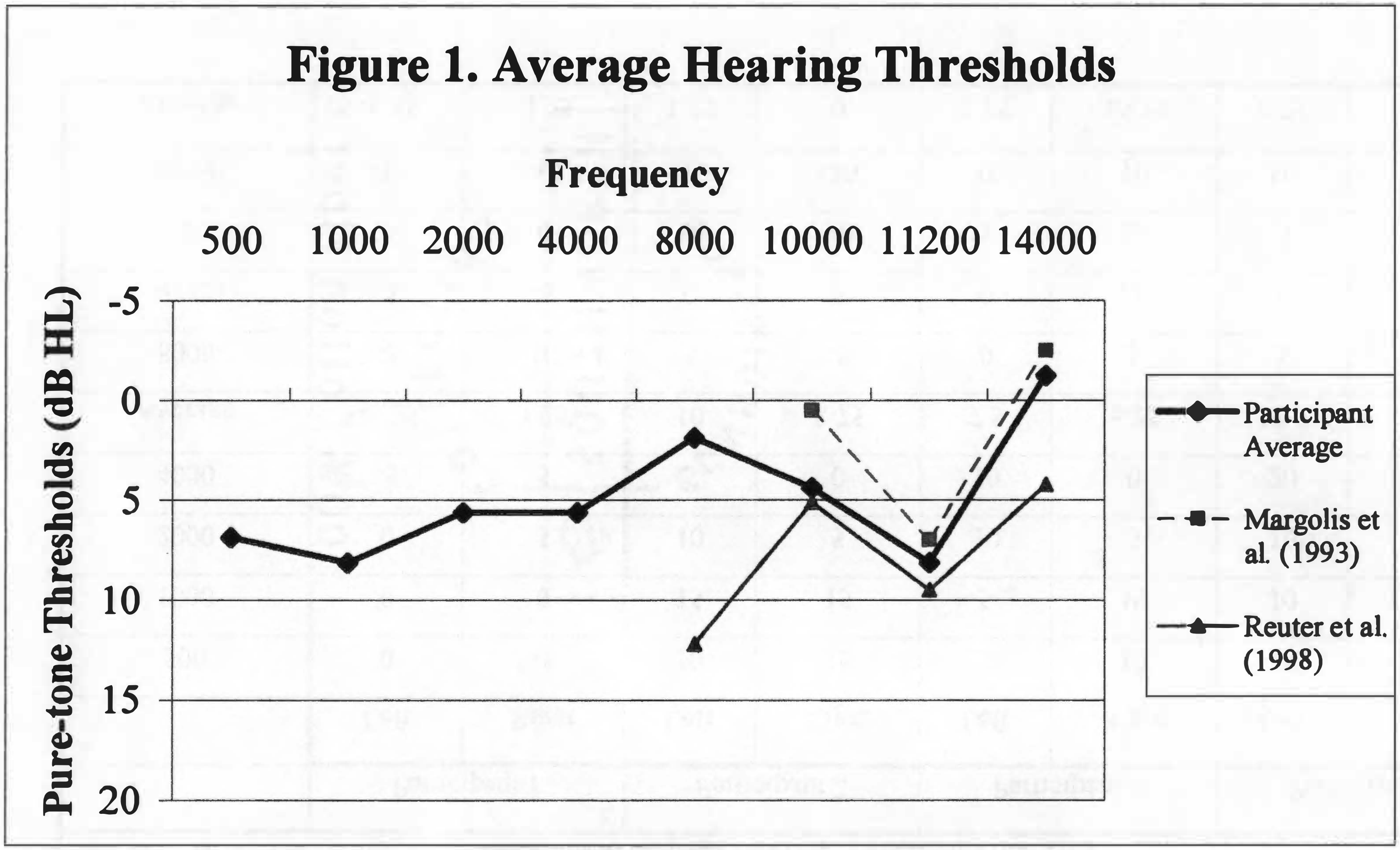


Figure 1: Average hearing thresholds

Table 4. Participant 1 Errors

Phoneme	Initial		Medial		Final	
	Single Words*	Conversation	Single Words*	Conversation	Single Words*	Conversation
d		_				_
t						_
n				_		_
l	w	w	w			
r		w	w			_
ń	_		f	f		
s			s̪	t		_
ð	d̪	d	d			
v	b	b	b			
h		_				
z				d		
pl	pw					
bl		l				
kl		kw				
kr		kw				
fr		f				
sl	fl					
sw	fw					
st		t				
sk		k				
sp	p					

*from the Goldman-Fristoe Test of Articulation -- 2nd edition (GFTA-2; Goldman & Fristoe, 2001)
-denotes deletion of target phoneme

Table 5. Participant 2 Errors						
Phoneme	Initial		Medial		Final	
	Single Words*	Conversation	Single Words*	Conversation	Single Words*	Conversation
t		_				_
n						_
l		_, r, w	w			
r		w, zw		w		_
ɚ				ə		ə
ð		_, j, d				
z						_
v						_
ʃ		tʃ				
s	s̪		t			_
bl	b	b				
pl		p				
tr	tw	tw				
fr		fw				
sp	p					
sk		k				
st		t				

*from the Goldman-Fristoe Test of Articulation -- 2nd edition (GFTA-2; Goldman & Fristoe, 2001)
-denotes deletion of target phoneme

Table 6. Participant 3 Errors						
Phoneme	Initial		Medial		Final	
	Single Words*	Conversation	Single Words*	Conversation	Single Words*	Conversation
d		_				
t						_
k					t	
m						_
n						_
l						_
r	w	w	w	_, w	_	_
ɚ				ə		ə,ɔ,_,ɪ
ɝ						ʌ
ʤ		d				
ð		_,d,v	v	v		
z			z̪			z̪
ń	s	s,f			f	
ʃ	s̪					
s	s̪		s̪		s̪	_
br	bw	bɔw				
dr	vw	dw				
fr	fw	k͓,f				
gr	gw	gw				
kr	kw	k͓				
tr	k͓r	t͓,kl,k͓				
bl	b					
sl	s̪					
st		s				
sp	s̪p					
spr		spw				

*from the Goldman-Fristoe Test of Articulation – 2nd edition (GFTA-2; Goldman & Fristoe, 2001)
-denotes deletion of target phoneme

Participant 2 had more consonants correct in single words (92%) than in conversation. Participant 3 had fewer consonants correct in single words (71%) than in conversation (71%). Values for conversation correspond to severity ratings of mild to moderate, mild, and mild, respectively (Shriberg & Kwiatkowski, 1992).

Fricatives

Participants 1 and 2 had more errors on fricatives in conversation than single words. Participant 3 had more errors on voiced fricatives (/ð, z/) in conversation than in single words. However, he had more errors on voiceless fricatives (/θ, s/) in single words than in conversation.

All participants misproduced some of the four fricatives /f, s, θ, ʃ/ in at least one context. All participants had difficulty producing /s/. Participants 1 and 3 had difficulty producing /θ/. Participants 2 and 3 had difficulty producing /ʃ/. None of the participants had difficulty producing /f/. In addition, all participants had some difficulty producing the voiced fricatives /ð/ and /z/. All participants also had difficulty producing /s/ clusters.

Participant 1 deleted the initial /θ/ in single words and produced /f/ for /θ/ in the medial position of words in both single words and conversation. He also dentalized the /s/ in the medial position of single words and produced /t/ for /s/ in the middle position of words in conversation. He also had difficulty producing the voiced fricatives /v/, /ð/ and /z/. He produced /v/ as /b/ in the initial position of words in single words and conversation, and the medial position of single words. He produced /ð/ as /d̪/ in the intial position of single words, as /d/ in the initial position of words in conversation, and as /d/ in the medial position of single words. Participant 1 also had difficulty with /s/ clusters producing /sl/ and /sw/ as /fl/ and /fw/ respectively. He deleted the /s/ in /s/ plus stop clusters (/sp, sk, st/).

Participant 2 also had difficulty producing the /s/ phoneme in single words. He dentalized the /s/ in the initial position, produced /t/ for /s/ in the medial position, and deleted the /s/ in the final position. However, these productions were not observed in conversation. Participant 2 also produced /ʃ/ for /tʃ/ in the initial position of words in conversation. Participant 2 also had difficulty producing the voiced fricatives /v/, /z/ and /ð/ in conversation but not in single words. He deleted the /v/ in the final position of words in conversation. He deleted the /z/ in the final position and inconsistently deleted or produced /ð/ as /ʤ/ and /d/ in the initial position. In addition, participant 2 deleted the /s/ in /s/ plus stop clusters (/sp, sk, st/).

Participant 3 had difficulty producing three of the four high frequency fricatives. Participant 3 dentalized the /s/ phoneme in all positions of single words and deleted the /s/ phoneme in the final position of words in conversation. He produced /s/ for /θ/ in the initial position and /f/ for /θ/ in the final position of single words. He produced /s/ and /f/ in the initial position of words in conversation. Participant 3 also produced /s̪/ for /ʃ/ in the initial position of single words. Participant 3 also had difficulty producing the voiced fricatives /ð/ and /z/. He produced /ð/ as /v/ in the medial position in both single words and words in conversation and inconsistently deleted or produced /ð/ as /d/ or /v/ in the initial position of words in conversation. He dentalized /z/ in the medial position of single words and the final position of words in conversation. He also had difficulty with /s/ clusters producing /sl/ as /s̪/, /st/ as /s/, /sp/ as /s̪p/, and /spr/ as /spw/.

Other Errors

All participants had more errors in conversation than in single words on other phonemes. Participant 1 deleted /d/ and /h/ in the initial position, /n/ in the medial position, and /d/, /t/, /n/, and /r/ in the final position of words in conversation. He produced /l/ as /w/ in the initial position of single words. He also produced the liquids /l/ and /r/ as /w/ in the initial position of words in conversation and the medial position of words. He produced the stop plus /l/ clusters, /pl/ and /kl/ as /pw/ and /kw/, but /bl/ as /l/. He produced /kr/ as /kw/ and /fr/ as /f/.

Participant 2 deleted /t/ in the initial position of words. He also deleted /t/, /n/, and /r/ in the final position of words in conversation. He had difficulty producing the liquids /l/ and /r/. He inconsistently deleted or produced /l/ as /r/ or /w/ in the initial position of words in conversation and as /w/ in the medial position of single words. He produced /ɚ/ as /ə/ in the medial and final position of words in conversation. He also reduced stop plus /l/ clusters (e.g. /bl/ as /b/) and produced stop plus /r/ clusters as stop plus /w/ (e.g. /tr/ as /tw/).

Participant 3 deleted /d/ in the initial position of words, and /t/, /m/, /n/, /l/, and /r/ in the final position of words in conversation. He also deleted /r/ in the final position of single words. He produced /k/ as /t/ in the final position of single words. He produced /r/ as /w/ in the initial and medial position of both single words and words in conversation. He inconsistently deleted the /r/ in the medial position of words in conversation. He produced /ɚ/ as /ə/ in the medial position of words in conversation and inconsistently deleted or produced /ɚ/ as /ə, ɪ/ and /ɔ/ in the final position. He also produced /ɝ/ as /ʌ/ in the final position of words in conversation. He produced /d/ as /ʤ/ in the initial position of words in conversation. Participant 3 also had difficulty producing stop plus /r/ clusters. He produced /br/ as /bw/ in single words and as /bɔw/ in words in conversation. He produced /dr/ as /vw/ in single words, and as /dw/ in words in conversation. He produced /fr/ as /fw/ in single words and inconsistently as /k͓/or /f/ in words in conversation. He produced /gr/ as /gw/ in single words and words in conversation. He produced /kr/ as /kw/ in single words and as /k͓/ in words in conversation. He produced /tr/ as /k͓r/ in single words and inconsistently as /t̽/, /kl/, and /k̽/ in words in conversation. He also produced /bl/ as /b/ in single words.

Speech Perception

Only one participant had difficulty with the speech perception task. Participant 1 performed poorly on the SP-PT. He had difficulty perceiving the fricatives /f/ and /ń/, but no difficulty with /s/ and /ʃ/. Recall that participant 1 had a diagnosis of attention deficit hyperactivity disorder (ADHD) as well as otitis media. He was brought back a third day for retesting of perception because it was felt he was losing attention by the time speech perception was tested on day 2. However, he still performed poorly on day 3 when it was felt he was more attentive.

All other participants perceived the fricatives /s, f, ʃ, ń/ without any problems. The results of the SP-PT are shown in Table 7.

Perception versus Production

Participant 1 (the only participant with speech perception problems) also had difficulty producing the /s/ and /θ/ phonemes (see above).

Table 7: Percentage of Errors on SP-PT

Participant #	/f/ vs /θ/	/f/ vs /s/	/θ/ vs /s/	/s/ vs /ʃ/	/ʃ/ vs /θ/
1	66%	0%	0%	0%	0%
2	0.08%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%
4*	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed

* Participant 4 did not participate in day 2 of testing

CHAPTER 5

DISCUSSION

Question 1. EHF Hearing and Speech Delay

The first question in this study was whether children with speech delay of unknown origin have reduced hearing acuity in the EHF range. It was found that, although all participants had speech delay of unknown origin, three of the four participants did not have reduced EHF hearing acuity. Participant 3 had reduced EHF hearing acuity in one ear. He also had the lowest percentile rank on his current GFTA-2, suggesting that his speech delay was more severe than the other three participants. In addition, participant 3 had tympanostomy tubes bilaterally. Tonndorf and Khanna (1972) reported that the tympanic membrane breaks into sectional vibrations at higher frequencies. Therefore, it is possible that the location of the tympanostomy tube in the right ear affected the ability of participant 3 to hear the EHF frequencies presented.

Participant 3 had an asymmetry index of 15 dB, suggesting his EHF hearing acuity in his right ear was more reduced than in his left ear. It has been suggested that children with unilateral hearing loss have difficulty discriminating speech in noisy environments, especially when there is competing noise in the better ear (Bess, 1986; Bess, Klee, & Culbertson, 1986; Brookhouser, Worthington, & Kelly, 1991; Cozad, 1977). Therefore, participant 3 may have a more severe speech delay because of difficulty understanding speech during the critical period of speech development. This is speculation at this point because the research was confined to unilateral hearing loss in the conventional frequencies however. There does not appear to have been any research as to the effects of unilateral EHF hearing loss.

Question 2. EHF Hearing and Specific Speech Errors

The second question in this study examined whether children with speech delay of unknown origin and who have not acquired the high frequency sounds (/s/ and /z/)

have reduced hearing acuity in the EHF. All of the children in the current study had difficulty producing /s/ and /z/. Participant 1 also had errors on /θ/ and participant 2 had additional errors on /ʃ/. Participant 3 also had errors on other high frequency fricatives including /θ/ and /ʃ/. Only participant 3 had reduced hearing acuity in the EHF.

Various reasons might account for the speech delay being experienced by the children in the current study. It is therefore possible that participant 3 had difficulty with the fricatives /s,z,ʃ/ and /θ/ because of his hearing loss in the extended high frequencies. Several studies show that there is acoustic energy at these high frequencies (Bauer & Kent, 1987; Flipsen et al., 1999; Pentz, 1996; Pentz et al., 1979). The inablility to hear this energy could have prevented the development of these phonemes. However, due to the small sample size, this cannot be determined with any certainty from the current study.

Question 3. EHF Hearing, Speech Delay, and Otitis Media

The third question examined in this study was whether children with speech delay of unknown origin and a history of otitis media have reduced hearing acuity in the extended high frequencies. Two of the participants had a history of otitis media. Participant 1 only reported a history of otitis media but the extent of this history was not known. Participant 3 reported a history of allergies accompanied by sinus and ear infections several times a year. Both participants 1 and 3 had tympanostomy tubes inserted prior to age 4;6 and participant 3 had a second set of tubes inserted at age 5;9. Based on this information, it appears that participant 3 had a more significant history of otitis media. In addition, participant 2 reported removal of his tonsils and adenoids which may suggest unreported or undiagnosed history of otitis media for this participant. Participant 3 had reduced hearing acuity in the extended high frequencies, but participants 1 and 2 did not. Several studies have reported the presence of hearing loss in the extended high frequencies in children with acute otitis media (Ahonen & McDermott, 1984; Hunter et al., 1996; Laitila et al., 1997; Lopponen et al., 1992; Margolis et al., 1993; Margolis et al., 2000; McDermott, et al., 1986). It is possible that more severe or chronic cases of otitis media result in reduced hearing acuity in the extended high frequencies. However, since the extent of otitis media history in participants 1 and 2 was unknown, this could not be determined from the current study.

In addition to an increased risk of EHF hearing loss associated with otitis media, it has also been reported there is an increased risk of speech delay associated with otitis media (Shriberg et al., 2000). When chronic otitis media results in hearing loss in the EHF range, the child may have problems producing speech sounds that have acoustic energy at in the EHF. Participant 3 had reduced EHF hearing acuity and a history of chronic otitis media. Therefore, this suggests that for participant 3 his speech delay may have been a result of chronic otitis media.

EHF and Speech Perception

Participant 1 had decreased ability to perceive the difference between /f/ and /θ/, but not /s/ and /ʃ/. In addition, he did not have a reduced hearing acuity in the EHF range or in the conventional range. His perception problem may have been due to lack of attention. Recall that he had been diagnosed as having attention deficit hyperactivity disorder (ADHD). The stridents (/s/ and /ʃ/) have a greater noise energy than the nonstridents (/f/ and /θ/). This difference in amplitude has been considered to be an important perceptual factor (Kent & Read, 1992). Because of this amplitude difference, perceiving the difference between the fricatives /f/ and /θ/ may have required greater attention therefore resulting the perception difficulty participant 1 had with these particular sounds.

Participant 3 had a reduced EHF hearing acuity and did not have any difficulty perceiving the sounds that contain EHF energy (/s, ʃ, f, θ/). Therefore, there does not appear to be a relationship between EHF hearing and speech perception, at least for the children in the current study.

The unilateral nature of the EHF hearing loss in participant 3 raises a question. Several researchers (Bess, 1986; Bess, et al., 1986; Brookhouser, et al., 1991; Cozad, 1977) have found that children with unilateral hearing loss have difficulty discriminating speech in noisy environments due to a reduced signal to noise ratio. If this research holds true with unilateral EHF hearing loss as well, this participant might have difficulty with speech perception in noise. This was not examined in the current study. However, participant 3 had a small asymmetry index, which may not have been a sufficient hearing loss to result in this perception difference.

Several studies (Bauer & Kent, 1987; Flipsen et al., 1999; Pentz, 1996; Pentz et al., 1979) have found that there is spectral information above 8000 Hz in children's production of fricatives. Because of their short vocal tracts, children produce fricatives at a higher frequency than adults. The SP-PT was administered to the participants via an adult model. The energy of the fricatives produced by the adult model may have been in the conventional hearing range. Participant 3 had normal hearing in the conventional range. If the SP-PT had been administered with a child model, participant 3 may have had difficulty perceiving these fricatives.

Clinical Implications

The relationship between speech delay and EHF hearing could not be determined from the current study due to the small sample size. The child in the current study who had an EHF hearing loss also had a significant history of otitis media and had the most severe manifestation of speech delay. Research suggests that EHF hearing may be related to the severity of otitis media (Margolis et al., 1993). In addition, research suggests that increased incidence of otitis media is associated with poorer EHF hearing (Ahonen & McDermott, 1984; Laitila et al., 1997; McDermott et al., 1986). Hunter et al. (1996) also suggested a decrease in EHF hearing associated with multiple tympanostomies. The current study supports this research.

If speech delay that includes problems with high frequency sounds is caused by reduced hearing acuity in the extended high frequencies, these frequencies should be assessed in audiologic examinations of children errors in these frequencies. In addition, amplification of these high frequencies may prove to be valuable to help these children to learn to produce these sounds.

Conclusions

The results of this study suggest that some children with otitis media and speech delay may have a hearing loss in the EHF range. However, due to the small sample size, this relationship cannot be determined from the current study. This hearing loss could be due to the otitis media. It is possible that the reduced hearing acuity in the extended high frequencies is related to the severity of otitis media history. This cannot be determined from the current study however because of the small sample size and the lack of information about the severity of otitis media for participants 1 and 2.

It remains unknown whether the spectral information above 8000 Hz is necessary for learning to produce fricatives. Although participant 3 had the most difficulty producing these fricatives and had reduced hearing acuity in the extended high frequencies, participants 1 and 2 also had difficulty producing some of the fricatives and did not have a hearing loss in the extended high frequencies. It is possible that there are multiple causes for speech delay, which may include reduced hearing acuity in the EHF range, chronic otitis media, and other factors (Shriberg, Austin, Lewis, McSweeny, & Wilson, 1997)

It appears that EHF hearing is unrelated to perception of fricatives. Participant 1 had difficulty perceiving /f/ and /θ/, yet did not have a reduced hearing acuity in the extended high frequencies. In addition, participant 3 had a reduced hearing acuity in the extended high frequencies, yet did not have difficulty perceiving any of the fricatives. The possibility that the use of a child model might have altered the current findings should also be investigated.

Further research is needed in order to determine the nature of the relationship between speech delay and EHF hearing. It would be interesting to examine whether EHF hearing loss causes speech delay on speech sounds that contain energy in the EHF range (/s, f, ʃ, θ/) with a larger sample. Future research should ask if chronic otitis media causes reduced EHF hearing acuity, and if so, does this reduced hearing acuity result in speech delay?

In addition, future research should ask if reduced EHF hearing acuity affects the perception of certain sounds containing high frequencies while other sounds containing high frequencies remain in tact. It would also be interesting to know if unilateral EHF hearing loss affect speech discrimination in the same way unilateral hearing loss at conventional frequencies affects speech discrimination. That is, would unilateral EHF hearing loss affect speech discrimination in noisy situations, but not in quiet?

REFERENCES

REFERENCES

Ahonen, J. E., & McDermott, J. C. (1984). Extended high-frequency hearing loss in children with cleft palate. Audiology, 23, 467-476

Allison, G. (1975). The relationship between articulation disorders and self-monitoring auditory discrimination. Journal of Communication Disorders, 8, 349-356

American National Standards Institute, Inc. (1996). Specification for Audiometers.

Bauer, H. R., & Kent, R. D. (1987). Acoustic analysis of infant fricatives and trill vocalizations. Journal of the Acoustical Society of America, 81(2), 505-511

Bernthal, J. E. & Bankson, N. W. (1998). Articulation and Phonological Disorders (4th ed.) Boston, MA: Allyn and Bacon.

Bess, F. H. (1986). The unilaterally hearing-impaired child: A final comment. Ear and Hearing, 7 (1), 52-54

Bess, F. H., Klee, T. & Culbertson, J. L. (1986). Identification, assessment, and management of children with unilateral sensorineural hearing loss. Ear and Hearing, 7 (1), 43-51

Brookhouser, P. E., Worthington, D. W., & Kelly, W. J. (1991). Unilateral hearing loss in children. Laryngoscope, 101, 1264-1272

Buren, M., Solem, B. S., & Laukli, E. (1992) Threshold of hearing (0.125—20kHz) in children and youngsters. British Journal of Audiology, 26, 23-31

Compton, A. J. (1970). Generative studies of children's phonological disorders. Journal of Speech and Hearing Disorders, 35, 315-339

Cozad, R. L. (1977). Speechreading skill and communication difficulty of children and young adults with unilateral hearing loss. The Journal of Auditory Research, 17, 25-29

Dreschler, W. A., v.d. Hulst, R. J. A. M., Tange, R. A., & Urbanus, N. A. M. (1985). The role of high-frequency audiometry in early detection of ototoxicity. Audiology, 24, 387-395

Dunn & Dunn (1997). Peabody Picture Vocabulary Test—Third Edition. Circle Pines, MN: American Guidance Service

DuBois, E. M., & Bernthal, J. E. (1978). A comparison of three methods for obtaining articulatory responses. Journal of Speech and Hearing Disorders, XLIII, 295-305

Eilers, R. E., & Oller, D. K. (1975). The role of speech discrimination in developmental sound substitutions. Child Language, 3, 319-329

Fausti, S. A., Erickson, D. A., Frey, R. H., Rappaport, B. Z. & Schechter, M. A. (1981). The effects of noise upon human hearing sensitivity from 8000 to 20000 Hz. Journal of the Acoustical Society of America, 69 (5), 1343-1349

Fausti, S. A., Frey, R. H., Erickson, D. A., Rappaport, B. Z., Cleary, E. J., & Brummet, R. E. (1979). A system for evaluating auditory function from 8000 to 20000 Hz. Journal of the Acoustical Society of America, 66 (6), 1713-1718

Flipsen, P. Jr., Shriberg, L., Weismer, G., Karlsson, H., & McSweeny, J. (1999). Acoustic characteristics of /s/ in adolescents. Journal of Speech, Language, and Hearing Research, 42, 663-677

Goldman, R. & Fristoe, M. (1986). Goldman-Fristoe Test of Articulation. Circlie Pines, MN: American Guidance Service

Goldman, R. & Fristoe, M. (2001). Goldman-Fristoe Test of Articulation—Second Edition. Circle Pines, MN: American Guidance Service

Harris, J. D., & Ward, M. B. (1967). High-frequency audiometry to 20 kc/s in children of age 10-12 years. The Journal of Auditory Research, 7, 241-252

Hoffman, P. R., Daniloff, R. G., Bengoa, D., & Schuckers, G. H. (1985). Misarticulating and normally articulating children's identification and discrimination of synthetic [r] and [w]. Journal of Speech and Hearing Disorders, 50, 46-53

Hunter, L. L., Margolis, R. H., Rykken, J. R., Le, C. T., Daly, K. A., & Giebink, G. Scott (1996). High frequency hearing loss associated with otitis media. Ear and Hearing, 17, 1-11

Kent, R. D., & Read, C. (1992). The Acoustic Analysis of Speech. San Diego, CA: Singular Publishing Group, Inc.

Laitila, P., Karma, P., Sipila, M., Manninen, M., & Rahko, T. (1997). Extended high frequency hearing and history of acute otitis media in 14-year-old children in Finland. Acta Otolaryngology, (Suppl. 529), 27-29

Locke, J. L. (1980a). The inference of speech perception in the phonologically disordered child. Part I: A rationale, some criteria, the conventional tests. Journal of Speech and Hearing Disorders, XLV, 431-444

Locke, J. L. (1980b). The inference of speech perception in the phonologically disordered child. Part II. Some clinically novel procedures, their use, some findings. Journal of Speech and Hearing Disorders, 45 (4), 445-468

Lof, G. L., & Synan, S. T. (1997). Is there a speech discrimination/perception link to disordered articulation and phonology? A review of 80 years of literature. Contemporary Issues in Communication Sciences and Disorders, 24, 63-77

Lopponen, H., Sorri, M., Pekkala, R., & Penna, J. (1992). Secretory otitis media and high frequency hearing loss. Acta Otolaryngology, (Suppl 493), 99-107

Margolis, R. H., Rykken, J. R., Hunter, L. L., & Giebink, G. S. (1993). Effects of otitis media on extended high-frequency hearing in children. Annals of Otolaryngology Rhinology, and Laryngology, 102, 1-5

Margolis, R. H., Saly, G. L., & Hunter, L. (2000). High-frequency hearing loss and wideband middle ear impedance in children with otitis media histories. Ear and Hearing, 21, 206-211

McDermott, J. C., Fausti, S. A., & Frey, R. H. (1986). Effects of middle-ear disease and cleft palate on high-frequency hearing in children. Audiology, 25, 136-148

McGregor, K. K., & Schwartz, R. G. (1992). Converging evidence for underlying phonological representation in a child who misarticulates. Journal of Speech and Hearing Research, 35, 596-603

Morrison, J. A. & Shriberg, L. D. (1992). Articulation testing versus conversational speech sampling. Journal of Speech and Hearing Research, 37(4), 935-937

Nittrouer, S. (2002). Learning to perceive speech: How fricative perception changes, and how it stays the same. Journal of the Acoustical Society of America, 112 (2), 711-719

Nittrouer, S., & Miller, M. E. (1997). Developmental weighting shifts for noise components of fricative-vowel syllables. Journal of the Acoustical Society of America, 102 (1), 572-580

Owens, R. E., Jr. (1996). Language Development: An Introduction (4^{th} ed.) Boston, MA: Allyn and Bacon

Pentz, A. (1996, November) Developmental changes in school-age children's fricative specra: Preliminary findings. Poster session presented at the Annual Convention of the American Speech-Language-Hearing Association, Seattle, WA.

Pentz, A., Gilbert, H. R., & Zawadski, P. (1979). Spectral properties of fricative consonants in children. Journal of the Acoustical Society of America, 66 (6), 1891-1893

Perozzi, J. A., & Kunze, L. H. (1971). Relationship between speech sound discrimination skills and language abilities of kindergarten children. Journal of Speech and Hearing Research, 14, 382-390

Reuter, W., Schonfeld, U., Mansmann, U., Fischer, R., & Gross, M. (1998) Extended high frequency audiometry in pre-school children. Audiology, 37, 285-294

Rvachew, S., & Jamieson, D. G. (1989). Perception of voiceless fricatives by children with a functional articulation disorder. Journal of Speech and Hearing Disorders, 54, 193-208

Scheter, M. A., Fausti, S. A., Rappaport, B. Z., & Frey, R. H. (1986) Age categorization of high-frequency auditory threshold data. Journal of the Acoustical Society of America 79 (3), 767-771

Sherman, D. & Geith, A. (1967). Speech sound discrimination and articulation skill. Journal of Speech and Hearing Research, 10, 277-280

Shriberg, L. D. (1986). PEPPER. Programs to examine phonetic and phonologic evaluation records. Hillsdale, NJ: Lawrence Erlbaum

Shriberg, L. D. (1994) Five subtypes of developmental phonological disorders. Clinics in Communication Disorders, 4(1), 38-53

Shriberg, L. D., Austin, D., Lewis, B. A., McSweeny, J. L., & Wilson, D. L. (1997). The speech disorders classification system (SDCS): extensions and lifespan reference data. Journal of Speech, Language, and Hearing Research,40(4), 723-740

Shriberg, L. D., Flipsen, P., Jr., Thielke, H., Kwiatkowski, J., Kerby, M. K., Katcher, M. L., Nellis, R. A., & Block, M. G. (2000). Risk for speech disorder associated with early recurrent otitis media with effusion: Two retrospective studies. Journal of Speech, Language, and Hearing Research, 43, 79-99

Shriberg, L. D., & Kent, R. D. (1995). Clinical Phonetics (2nd ed.). Boston, MA: Allyn & Bacon

Shriberg, L. D., & Kwiatkowski, J. (1982). Phonological disorders III: A procedure for assessing severity of involvement. Journal of Speech and Hearing Disorders, 47, 242-256

Stach, B. A. (1988). Clinical Audiology: An Introduction. San Diego, CA: Singular Publishing Group, Inc.

Stelmachowicz, P. G., Beauchaine, K. A., Kalberer, A., & Jesteadt, W. (1989) Normative thresholds in the 8- 20-kHz range as a function of age. Journal of the Acoustical Society of America, 86 (4), 1384-1391

Stelmachowicz, P. G., Gorga, M. P., & Cullen, J. K. (1982). A calibration procedure for the assessment of thresholds above 8000 Hz. Journal of Speech and Hearing Research, 25, 618-623

Stevens, K. N., Berkovitz, R., Kidd, G., & Green, D. M. (1987). Calibration of ear canals for audiometry at high frequencies. Journal of the Acoustical Society of America, 81 (2), 470-484

Strickland, E. A., & Viemeister, N. F. (1994). Is useful speech information carried by fibers with high characteristic frequencies. Journal of the Acoustical Society of America, 95 (1), 497-501

Templin, M. D. (1957) Certain languageskills in children, their development and interrelationships. Institute of Child Welfare Monograms, Ser. 26, Minneapolis: University of Minnesota Press

Templin, M. D. & Darley, F. (1960). The Templin-Darley Test of Articulation. Iowa City, Iowa: University of Iowa

Tonndorf, J., &Khanna, S. M. (1972). Tympanic-membrane vibrations in human cadaver ears studied by time-averaged holography. Journal of the Acoustical Society of America, 52, 1221-1233

Trehub, S. E., Schneider, B. A., Morrongiello, B. A., & Thorpe, L. A. (1989). Developmental changes in high-frequency sensitivity. Audiology, 28, 241-249

Vassalo, L., Sataloff, J., & Menduke, H. (1968). Very high frequency audiometric technique. Arch Otolaryngoly, 88, 49-51

Velleman, S. L. (1988). The role of linguistic perception in later phonological development. Applied Psycholinguistics, 9, 221-236

Zimmerman, I. L., Steiner, V. G., & Pond, R. E. (1992). Preschool Language Scale-Third Edition. San Antonio, TX : The Psychological Corporation

Zislis, T. E., & Fletcher, J. L. (1966). Relation of high frequency thresholds to age and sex. The Journal of Auditory Research, 6, 189-198

APPENDICES

APPENDIX A

INFORMED CONSENT STATEMENT

Child's Name ________________________________ Child's Age ______________

Extended High Frequency Hearing in Children with Speech Delay of Unknown Origin

You and your child are invited to participate in a research study for a student master's thesis. The purpose of this study is to examine how well children with speech delay of unknown origin hear very high frequency sounds. We are interested in knowing if their hearing in this range differs from children without delayed speech. This may help us understand why some children have difficulty learning speech.

GENERAL INFORMATION.

Procedure: This study will involve your child interacting with the speech pathology student who is doing the thesis and doing the following things:

1. having a test to see if there is any fluid in their ears, and
2. having a standard hearing screening, and
3. having a test to see how well they can hear very high frequency sounds, and
4. having a 10-15 minute conversation, and
5. pronouncing the names for a series of colorful pictures of common things, and
6. having their face and mouth examined, and
7. taking a test of how well they know common words, * and
8. taking a test of whether they can hear the difference between pairs of words.

* this test may already have been given to your child recently. If this is so, we won't repeat the test but will use the results in your child's file in the UT Hearing and Speech Center.

Testing will be carried out in a sound-treated booth. You may watch all the testing if you wish. Tasks 4 and 5 will be tape-recorded. The microphone to make the recordings will be on the table near your child.

In addition to the above you will be asked to complete a form describing your child's developmental history. If you have already done this for the Hearing and Speech Center we will use the information from the form you have previously completed.

Time Required for Participation. Testing should take a total of about 2 hours of your child's time. We will do the first 3 tasks on 1 day and the other 5 tasks on a second day.

RISKS

There are no known risks from any of these procedures.

BENEFITS

Results of this study may help us understand why some children may have trouble learning to produce speech sounds. Other than helping us with that, your child will not receive any specific benefit from participating in this study.

(See back of page)

CONFIDENTIALITY

The information in the study records will be kept confidential. Data will be stored securely and will be made available only to persons conducting the study unless you specifically give permission in writing to do otherwise. No reference will be made in written or oral reports which could link you or your child to the study.

Tape recordings of the testing sessions will be marked only with an identification number and kept separately from any other information on your child. We will keep the recording until after we have completed our analysis but for no more than 3 years. The tapes will then be destroyed.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the faculty advisor of the student doing the thesis, Dr. Peter Flipsen Jr. at 425 South Stadium Hall on the University of Tennessee, Knoxville campus by phone at (865) 974-0354. If you have questions about your rights as a participant, contact the University of Tennessee Compliance Section of the Office of Research at (865) 974-3466.

PARTICIPATION

Your child's participation in this study is voluntary; you or your child may decline to participate without penalty. If you decide to permit your child to participate, **your child may withdraw from the study at any time** and it will not affect any services that your child receives or any other benefits to which your child is otherwise entitled. If you or your child withdraw from the study before data collection is completed your child's data will be returned to you or destroyed.

I agree to have my child participate in this study.

Parent's signature ______________________________ Date _________________

I also agree to having the audiotape recordings of my child stored securely in room 425 South Stadium Hall at the University of Tennessee until the analysis of the data is complete. I also understand that the tapes will be kept for no more than 3 years and then destroyed.

I have read and understand the above information. I have received a copy of this form.

Parent's signature ______________________________ Date _________________

Investigator's signature __________________________ Date _________________

APPENDIX B

PRE-ASSESSMENT QUESTIONNAIRE

The University of Tennessee
Hearing and Speech Center
1600 Peyton Manning Pass
Knoxville, TN 37996-2500
(865) 974-5451

I. CLIENT INFORMATION

Child's Name ____________________ Birthdate ________ Sex ______

Address ____

____

II. FAMILY INFORMATION

Father's Name ____________________ Birthdate ____________

Street/Apt. No. ____________________ County ____________

City ____________________ State __________ Zip ____________

Employer ____________________ Occupation ____________

Home Phone ____________________ Work Phone ____________

Mother's Name ____________________ Birthdate ____________

Street/Apt. No ____________________ County ____________

City ____________________ State __________ Zip ____________

Employer ____________________ Occupation ____________

Home Phone ____________________ Work Phone ____________

Marital Status: Married_____ Separated_____ Divorced_____ Widowed_____ Unmarried_____

List children and adults (other than parents) who live in child's home:

Name ____________________ Age_____ Relationship ____________________

Name ____________________ Age_____ Relationship ____________________

Name ____________________ Age_____ Relationship ____________________

Name ____________________ Age_____ Relationship ____________________

III. COMMUNICATION INFORMATION:

At what age did your child:

babble____________________ say single words__________________________

say 2-3 word sentences____

Is there a family history for speech difficulties_____ If so, please describe:__________

____

Describe your child's communication difficulties as completely as possible____________

____

____

____

When was this difficulty first noted?____________________________________

____

When does your child communicate best?_________________________________

____

How does your child communicate with another child?_______________________

____

a familiar adult?____

____

an unfamiliar adult?____

a small group?____

IV. MEDICAL INFORMATION:

Name of pediatrician or family physician:______________________________

Were there problems during pregnancy, labor or delivery?____________________

If so, please describe:____

____

Did the baby have problems after birth? (jaundice, low birth

weight, breathing problems)______________________________________

____

Did the baby have any sucking or feeding difficulties?______________________

If so, please describe:____

____

If a toddler, does your child have feeding difficulties? (choking, food preferences)________

____

Is your child taking any medication regularly?______ If so, please list:________________

____

Has your child had any major illnesses or injuries?_____ If so, please describe:_________

____

Has your child had a history of common childhood illnesses, such as chicken pox, measles, etc.?_______ Any complications (high fever hospitalizations)?______________________

____

Does your child have a history of ear infections?___If so, how many in the last 6-12 months?

____

Does your child have a history of allergies, colds, upper respiratory infections?______ If so, please describe:____

____

____

V. DEVELOPMENTAL/SOCIAL INFORMATION:

At what age did your child: roll over__________ sit alone__________

pull up __________ crawl__________ walk__________

How does your child play with other children?__________

____

How does your child get along with familiar adults?__________

____

unfamiliar adults?__________

____

What activities does your child enjoy?__________

____

____

What activities does your child dislike?__________

____

____

Do you have any concerns about your child's behavior?__________

____

____

Compared to other children your child's age, describe how your child is able to sit, stand, run, use his/her hands. Any clumsiness or other problems?__________

____

____

Please outline a schedule of activities that your child carries out on a typical day.__________

____

____

VI. PRESCHOOL/SCHOOL INFORMATION:

Does your child currently attend a: Nursery____________Daycare _______________

Preschool______ If so, where?____

____

Do you have any concerns about your child's performance in

preschool or school?_____________ If so, please explain:_____________________

____

Does your child receive any special services (speech therapy, physical therapy, learning resource, special school class,

etc.)?_____ If so please list:____

____

Person completing this form____

Relationship to child__________________________________ Date_________

APPENDIX C

Oral-Facial Examination Checklist

(Adapted from a procedure by Robert Mason, PhD, DDS)

Patient ______________________________ Age _______ Sex _______

Date of Exam ____________________ Examiner ______________________________

A. External Structure and Symmetry (Front View) Answer Yes or No:

a. Face = 5 eyes wide? ___________ b. Upper face = lower face? ___________

c. Intercanthal width = alar base width? __________

d. Lip corners correspond to medial edges of iris? ________

e. Nasal ala of equal size and shape? ________ f. Columella complete ? __________

g. Philtrum defined? ________ h. Cupid's bow defined? _________

i. Lip incompetence? ________ j. Lower lip covers 2-3 mm of upper incisors? ________

k. Surgical scars? _________ If yes, specify ______________________________

(Lateral View)

a. Auditory meatus level with zygomatic arch? Left ________ Right ________

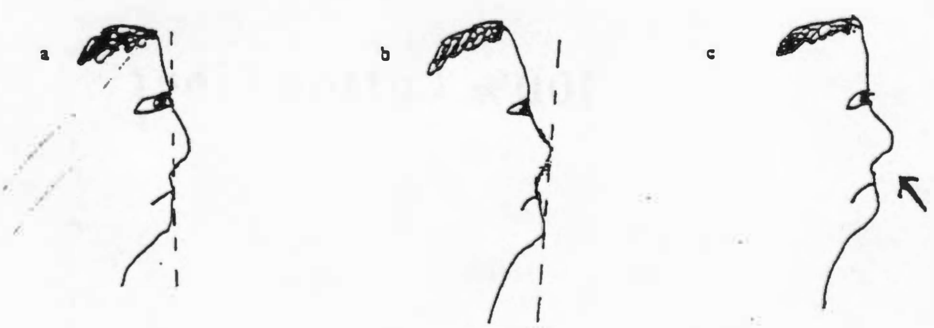
b. Pinna complete? Left ________ Right ________

c. Profile line [a] = straight or slightly convex? ________

d. Esthetic line [b] : Lips at or behind? ________ Lower lip slightly closer? ________

e. Naso-labial angle [c] = 90-110 degrees? ________

a b c



B. Internal Structure

1. Teeth

a. All present? Upper ________ Lower ________

b. List any missing teeth? ____

c. Occlusion? Left: Normal _______ Class II _______ Class III ________

Right: Normal _______ Class II _______ Class III ________

d. Overjet? ________ e. Underjet? ________ f. Crossbite? ________

g. Openbite? ________ h. Closedbite? ________

i. Upper incisor covering 1/3 to ½ of lower incisor? ________

2. Tongue

a. Tip at rest behind lower incisors? ________

b. Sides at rest siting atop lower back teeth? _______

c. Lingual frenum allows for adequate mobility? ________

3. Palate

a. Palatal vault: High and narrow? _______ Shallow and wide? _______

b. Torus palatinus present? ________ c. White or pinkish midline? ________

4. Velum

a. Symmetrical? ________ b. Uvula: Normal? ________ Bifid? ________

5. Tonsils

a. Present? ________ b. Cryptic (displace posterior fauces)? ________

C. Function Examination

1. External Function

a. Closing eyelids lightly? ________ Tightly? ________

b. Raising eyebrows? ________ c. Pursing lips (alternate /u/ and /i/)? ________

d. Puffing out cheeks? ________ Resisting external pressure? ________

e. Shrugging shoulders? ________ f. Lowering jaw? ________

2. Tongue / Velar Function

a. Accuracy (repeat 5; normal speed): /p/ _______ /t/ ______ /k/ ______

b. Sequencing (repeat 5; normal speed): /ppt/ ______ /ptt/ _______

/ttk/ _____ /tkk/ _____ /ptk/ _____

c. Does velum elevate during prolongation of /a/? _________

3. Laryngeal / Respiratory Function

Prolongation of /a/ (record # of seconds): ________

Reference data:	Preschoolers	At least 5 seconds
	School-age children	At least 9 seconds
	Adults	At least 15 seconds

4. Additional Comments / Observations

____

____

____

____

Jan 2000

VITA

Mandi Carol Stutsy was born in Pontotoc, MS on February 19, 1979. During high school, she observed a speech language pathologist and became interested in the field. Mandi graduated from Pontotoc High School with special honors in May of 1997. After that, she attended Mississippi University for Women (MUW) where her major was Speech-Language Pathology. While in attendance at MUW, Mandi was a member of the Mortar Board and Phi Kappa Phi. In May, 2001, she received a Bachelor of Science degree from MUW. She graduated with Magna Cum Laude honors. In the fall of 2001, Mandi began graduate work at the University of Tennessee, Knoxville. Soon after defending her master's thesis, Mandi received a Master of Arts degree in speech-language pathology in May 2003.