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Speech Perception and Language Skills of Deaf Infants After Cochlear Implantation: A Review of Assessment Procedures and a Research Plan[1]

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Abstract. "Universal Newborn Hearing Screening" law will result in many more infants identified with hearing loss. Thus, many more infants will receive interventions such as cochlear implants at a very young age. In order to evaluate the benefits of receiving cochlear implants during infancy, speech perception and language skills of infants who receive cochlear implants must be assessed. However, most current procedures used to test infant speech perception and language skills have only been used with normal-hearing infants. This paper reviews procedures that have been used to assess sound detection (Behavioral Observation Audiometry (BOA) and Visual Reinforcement Audiometry (VRA)), speech discrimination (VRA, High Amplitude Sucking (HAS), Visual Habituation (VH) Procedure), word learning (VH and Preferential Looking Paradigm (PLP)), and sensitivity to regularities in the ambient language (Headturn Preference Procedure (HPP)). A research plan is outlined and described to adapt the PLP and VH procedures for use with infants who use cochlear implants.

Introduction

Over the past 30 years, technological advances in cochlear implants (CIs) have allowed a growing number of people who are profoundly deaf to perceive sound and understand speech. Hearing-impaired listeners with CIs often show remarkable skills in perceiving and understanding speech and producing spoken language (Dorman, Hannley, Dankowski, Smith, & McCandless, 1989; Miyamoto, Kirk, Robbins, Todd, & Riley, 1996). For instance, many post-lingually deafened adult CI users are able to converse over the telephone without additional sensory aids, and many prelingually deaf children with CIs appear to be able to acquire spoken language normally and enter mainstream school systems. The benefits observed from CI use have led to a broadening of candidacy criteria for receiving a CI. In 1990, the FDA approved CIs for prelingually deaf 2-year-old children. In 1998, this criterion was lowered to 18-month-olds. To accommodate this trend, researchers have developed several new behavioral techniques for evaluating CI benefits that are appropriate for younger and younger children (see Kirk, Diefendorf, Pisoni, & Robbins, 1997). For example, to assess word recognition skills of children who cannot yet read, several behavioral tests require children to point to pictures (as opposed to written words) that correspond to the words they are presented with auditorily (e.g., Geers, 1994).

While steady progress has been made in developing new assessment techniques for speech and language, at the present time, measuring and assessing these skills in children and infants who are too young to follow instructions has been extremely difficult. The only current methods of assessing outcome rely on parent questionnaires (Hayes & Northern, 1996). Having appropriate behavioral performance measures of spoken language skills for young CI users' is critical at this time for several reasons. Last year, the FDA lowered the age criterion for candidacy again -- this time down to 12-months of age. As a result, many infants in the U.S. can receive CIs well before the age at which current behavioral techniques are able to assess their speech perception and language skills. In Europe, infants younger than 6-months have been successfully implanted. Furthermore, position statements and guidelines from the Joint Committee on Infant Hearing (2000) and the American Academy of Pediatrics (1999) are persuading most state lawmakers into implementing "Universal Newborn Hearing Screening" laws, which require hospitals to test the hearing of all newborns. As newborn hearing screening is implemented in hospitals, many more young infants will be identified with a hearing loss and these children will become potential candidates for CIs. Measuring and tracking the perceptual and linguistic development of young prelingually deaf infants who receive CIs will be necessary to assess the possible benefits of performing the CI surgery at very young ages. However, the current battery of behavioral tests used to measure CI users' spoken language performance was designed for older children (≥ 2 years) and are clearly not appropriate for young infants (≤ 2 years). As the number of young infants who receive CIs increases, it is important that researchers and clinicians develop new methodologies and behavioral techniques to measure the perceptual and linguistic skills of infants and how these processes change over time.

In order to have a full description of the auditory, perceptual, and linguistic progress of infants who use CIs, several speech perception and language skills must be assessed using behavioral techniques. These skills include (but are not limited to): (1) *sound detection*, which is assumed to be a prerequisite for other auditory speech perception abilities (Geers & Moog, 1989); (2) *speech discrimination*, which is the ability to detect differences without necessarily understanding their significance; (3) *word-learning*, which requires the ability to recognize the sound patterns of words and associate them to their referents; and (4*) sensitivity to phonological regularities*, which involves the ability to store in long-term memory language-specific properties and sound patterns in the ambient language.

Over the past 30 years, several methods have been developed to investigate the speech perception and language skills of normal-hearing infants. While audiologists routinely assess hearing-impaired infants' ability to detect simple tones and speech sounds, no procedures have been established to assess hearing-impaired infants' speech discrimination, word learning abilities, and sensitivity to phonological regularities. The sections below briefly review methodologies that have been used to investigate these abilities in normal-hearing infants. A summary of current work-in-progress that employs two of these methodologies to assess speech perception and linguistic skills of profoundly deaf infants who use cochlear implants is provided at the end.

Infant Speech Perception Abilities and Methods of Assessment

Sound Detection

The two primary methods that audiologists use for assessing sound detection and auditory thresholds of infants are *Behavioral Observation Audiometry* and *Visual Reinforcement Audiometry*.

Behavioral Observation Audiometry (BOA). During a BOA procedure, the examiner presents sound out of sight from the infant, using either sound field signals or a manually operated noisemaker, and observes the infant's responses (Northern & Downs, 1991). The type of responses that audiologists look for from an infant depends on the infant's age. For infants between 0 and 4 months of age, an arousal response from sleep (e.g., eye opening, eye blink, movement in arms, legs or body) is the most common observation. Older infants are more likely to be awake during testing and are more likely to show a headturn toward the sound source (Watrous, McConnell, Sitton, & Fleet, 1975). The BOA is very easy to implement. However, many infants will respond to sound only a couple of times and then stop, presumably from boredom and habituation. Hence, it is often difficult for audiologists, using BOA, to assess infants' hearing levels at more than a few frequencies (Northern & Downs, 1991).

Visual Reinforcement Audiometry (VRA). The VRA is a method that relies on conditioning infants to orient to a reinforcer (Primus, 1992). The infant typically is seated with the caregiver in a sound booth while the audiologist is in a control room. In the booth is a reinforcer usually to one side of the infant, although sometimes there may be a reinforcer on both sides. Often, the reinforcer is a mechanical stuffed animal in a Plexiglas box, which can be illuminated and animated to keep the infant's interest (Moore, Thompson, & Thompson, 1975). A loudspeaker sits just below the reinforcer. Also, in the booth is an "attention-getter" directly in front of the infant to draw the infant's attention away from the side. Typically, the attention-getter is either a blinking light, a second mechanical stuffed animal, or an assistant or a parent entertaining the infant with silent toys (Gravel, 1997). The audiologist, assistant, and caregiver listen to masking music over headphones so they do not know which trials have the change and hence will not bias the infant looking toward the reinforcer.

At the beginning of each trial, the infant's attention is brought to the center by the attention-getter. During the conditioning phase, a tone that is considered likely to be well above the infant's auditory threshold is presented over a loudspeaker in the booth. The reinforcer is presented to the infant if s/he demonstrates an orienting response to the loudspeaker. If there is no orienting response during a trial, then no reinforcement is given. The intensity is increased until the infant orients to the loudspeaker. The idea is to build an association between the tone and the reinforcer (Thompson & Folsom, 1984). Once the infant is conditioned to look towards the reinforcer in response to sound, the audiologist presents lower intensities to assess the infant's auditory thresholds. Because head-turn responses in VRA are conditioned by an interesting reinforcer, infants usually stay engaged in VRA longer than in BOA, allowing audiologists to make more complete assessments (Hayes & Northern, 1996).

Speech Discrimination

Normal-hearing newborns are able to discriminate global, rhythmic properties of speech, and, by the first couple months of life, they are able to make fine-grained discriminations of phonemes and syllables (see Jusczyk, 1997 for a review). The most common behavioral procedures for assessing infants' speech discrimination abilities are the *Conditioned Head Turn Procedure* (a modified version of the VRA), the *High Amplitude Sucking Procedure*, and the *Visual Habituation Procedure*.

Conditioned Head Turn (CHT) Procedure. The CHT is identical to the VRA except that, rather than conditioning the infant to respond to the presence of sound, the experimenter conditions the infant to respond to a change in a sequence of speech stimuli. For example, Kuhl (1979) used this procedure to test infants' ability to discriminate vowels. One vowel was repeated several times (e.g., /i/, /i/, /i/) and then a different vowel was presented (e.g., /o/, /o/, /o/). Infants were rewarded with a visual reinforcer only when they responded to a vowel change. As with the VRA, the experimenters and caregiver listen to masking music over headphones during the procedure.

The CHT can be used with 5- to 18-month-olds, but it is most commonly used with 6- to 10-month-olds (Werker et al., 1998b). The CHT has three stages: (1) A *training stage*, in which the infant is presented with the reinforcer immediately after a new stimulus is presented; (2) a *conditioning stage,* in which the experimenter gradually introduces increasingly longer delay periods between change and reinforcer until the infant performs a criterion number of anticipatory head turns; and (3) a *test phase,* in which the computer randomly presents test and control trials (i.e., the vowel stays the same). Statistical analyses are used to see if infants are more likely to look to the reinforcer during test trials than during control trials. A significant difference in the predicted direction indicates that infants can discriminate the two sounds tested. One disadvantage of this procedure is that many infants do not complete the *conditioning phase* because they never meet the criterion of (usually) three anticipatory looks in a row. The attrition rate for this procedure is in the range from low (~5%) to quite high (~50%) (Werker et al., 1998b).

High Amplitude Sucking (HAS) Procedure. The HAS was originally developed to see if infants would change their sucking behavior in response to changes in visual stimuli (Siqueland & DeLucia, 1969). The procedure was then adapted for use in speech perception. The HAS was the procedure used in the very first infant speech perception experiment, which showed that 2-month-olds could discriminate differences in voice onset time between /ba/ and /pa/ (Eimas, Siqueland, Jusczyk, & Vigorito, 1971). The methodology has since been used to investigate young infants' ability to discriminate many other fine-grained phonetic contrasts (see Jusczyk, 1997 for review). HAS has also been used to show that newborns can discriminate between languages that are rhythmically different from each other (Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, 1998). The procedure can be used successfully with normal-hearing newborns up to 4-month-olds.

In the HAS, the infant is given a nonnutritive pacifier that is linked, via a pressure transducer, to a computer, which registers each strong sucking response. The assistant who holds the pacifier listens to masking music over headphones and is unaware of the experimental conditions the infant is assigned to. Presentation of speech stimuli is contingent on a sucking response, giving the infant control of the stimulus presentation rate. The experiment has three phases. During the *baseline phase,* the infant's baseline sucking rate (i.e. number of sucks per minute) is assessed without any speech stimuli. The sensitivity of the equipment is tailored to each infant so that the baseline sucking rate for all infants falls within a pre-established range (typically 15-35 sucks per minute). During the *habituation phase,* one stimulus type is presented until the infant's sucking rate slows and reaches a habituation criterion. The computer keeps track of the number of sucks per minute. In one version of the procedure (see Jusczyk, 1997), the infant must first exhibit a sucking rate above baseline on at least one trial before s/he is allowed to reach the habituation criterion. Habituation is reached as follows. The computer codes the first 1-minute trial above baseline as a "high" trial. The subsequent trial is a new high trial if the sucking rate is at least 75% of the previous trial. If the sucking rate is less than 75% of the previous high trial, then it is considered a "low" trial (i.e., two consecutive trials 75% or less than the previous high trial). The infant reaches the habituation criterion when s/he has two consecutive low trials. At this point, for infants in the experimental group, a new stimulus is presented during the *post-switch phase* for four 1-minute trials. Infants in the control group continue to hear the same stimuli during the *post-switch phase.* The differences in sucking rates between the first two trials of the *post-switch phase* and the last two trials of the *habituation phase* are compared for the experimental and control groups. A significantly greater sucking rate increase in response to the new stimuli after the stimuli are switched is interpreted to mean that infants can discriminate between the two types of stimuli.

The HAS has an even higher attrition rate than the CHT – about 50% or more. The experiment is stopped when infants fall asleep, begin to cry, do not meet the habituation criterion, or simply do not suck on the pacifier. However, because the HAS procedure uses sucking response, which is mastered soon after birth, rather than visual orientation, HAS remains the most common procedure for investigating speech perception of infants younger than 5 months (Jusczyk, 1997).

Visual Habituation (VH) Procedure. The VH procedure is based on the premise that infants will increase their visual fixation times in the presence of a novel stimulus. VH has long been used to investigate infant visual perception (e.g., Cohen, 1969; Kagan & Moss, 1965). In the mid-70s, Horowitz (1975) showed that infants will look longer at a visual display when they are listening to an interesting auditory stimulus. Since then, researchers have used visual habituation to design paradigms that test infant speech perception abilities. For example, VH has been used extensively to show that infants are able to discriminate between native and nonnative phoneme contrasts (e.g., Best, McRoberts, & Sithole, 1988; Polka & Werker, 1994). The basic idea is that over repeated presentations of a single auditory stimulus paired with a visual stimulus, visual fixation to the visual stimulus will eventually decrease. If a novel auditory stimulus is then presented with the same visual stimulus, and infants can discriminate the two auditory stimuli, then visual fixation times should increase (Horowitz, 1975; Werker et al., 1998b).

In the VH procedure, the infant is seated on the caregiver's lap in front of a TV monitor through which the visual and auditory stimuli are presented. There is very little else in the room to distract the infant. One experimenter is in a separate control room and manipulates the presentation of the stimuli. The infant's looks to the monitor are observed and recorded on a computer keyboard or with a button box in one of two ways. Either the first experimenter watches the infant via a closed-circuit video camera (placed inconspicuously in front of the infant) and monitor or a second experimenter, who is hidden from the infant, watches through peepholes. The experimenter(s) and caregiver listen to masking music over headphones.

The experiment has two main phases: habituation and test. At the beginning of each trial in both phases, the infant's attention is brought to the center with either a blinking light above the monitor or a graphic display presented on the monitor. When the infant looks at the monitor, the experimenter initiates a trial by pushing a button. During the habituation phase, the infant is presented with a simple visual display (e.g., a checkerboard pattern) and an auditory stimulus repeats (e.g., /da/, /da/, /da/...). The experimenter holds down the button as long as the infant continues to look at the monitor. When there is a look away, the experimenter releases the button but pushes it again if and when the infant looks back to the monitor. The stimuli continue until the infant looks away from the monitor for 1 second or more. When the trial ends, the center attention getting stimulus is presented again. The total time that the infant looks at the monitor is summed and recorded for each trial. The habituation trials continue until the infant reaches a habituation criterion. For example, the experimenter may set the habituation criterion to be three consecutive trials where the cumulated looking time for each trial is 50% or less than the average looking time of the first three trials.

In the VH procedure, there are at least two different ways that the experimenter can construct the test phase, depending on the design of the experiment. If the experimenter chooses a between-subjects design, then the trials in the test phase will all consist of either the same visual and auditory stimuli (control group) or the same visual display but different auditory stimuli (e.g., /ba/, /ba/, /ba/…) (experimental group). A difference is then calculated between the average looking time during the test phase and the average looking time during the final trials of the habituation phase. A significantly greater looking time difference between the experimental group and the control group is taken as evidence that infants can discriminate differences between the stimuli. A within-subjects design involves having both old and new stimuli during the test phase for each infant. For a within-subjects design, the order of the old and new stimuli trials must be counter-balanced across infants.

The VH procedure is currently the most commonly used habituation/dishabituation procedure for research on speech perception of infants. It has been used successfully with a wide age range of infants (2- to 14-month-olds). Another advantage of the VH procedure is that the attrition rate is relatively low (~20-25%). The procedure has also been extended to explore word-learning abilities (see below). For a more extensive review of the VH procedure, see Werker et al. (1998b).

Word Learning and Recognition

During the first year of life, infants' speech perception and language skills develop very rapidly. By five months of age, infants can not only discriminate speech sounds, but they can recognize very familiar sound patterns of words, such as their own names (Mandel, Jusczyk, & Pisoni, 1995). Infants also learn to associate the sound patterns of words to their referents. Recent findings have shown that infants begin to associate words to very familiar objects (e.g., their parents) by six months (Tincoff & Jusczyk, 1999), and, by 12-months, infants can identify the meaning of up to 50 words (Fenson et al., 1994). The VH has also been used by some researchers to assess word-learning abilities. Many researchers have used the Preferential Looking Paradigm and its variants to assess word learning and word recognition abilities.

Visual Habituation (VH) Procedure. Recently, a variation of the VH procedure has proven to be successful in exploring infant word learning (Stager & Werker, 1997; Werker, Cohen, Lloyd, Casasola, & Stager, 1998a). In this variation, infants are habituated to two visual object/auditory label pairs (e.g., V1-A1 and V2-A2). During the test phase, on half of the trials the infants are presented with the same pairings used during the habituation phase. On the other half of the trials, the pairings of visual objects and auditory labels are switched (e.g., V1-A2 and V2-A1). If infants are able to form associations between objects and labels, then they will demonstrate dishabituation (i.e. show longer looking times) to object/label mismatches.

Preferential Looking Paradigm (PLP). Thomas, Campos, Shucard, Ramsay, and Shucard (1981) showed that 1-year-olds will consistently fixate on objects longer when they hear the name of the object than when they hear a nonsense word. Using this basic finding, Golinkoff, Hirsh-Pasek, Cauley, and Gordon (1987) developed a procedure in which infants are presented with two objects side-by-side on TV monitors. At the same time the visual displays are presented, the name of one of the objects is presented several times over loudspeakers. For example, Tincoff & Jusczyk (1999) showed that when presented with an image of their mother on one side and their father on the other side, 6-month-olds will attend longer to the "correct" parent when hearing a synthesized voice repeating either *mommy* or *daddy*.

The standard set-up for the PLP consists of a single plain display wall (approximately 6'x6') with two square holes side-by-side to reveal two monitors and a third hole in the center that allows a video camera to record the infant's looking responses. The infant is seated on the caregiver's lap approximately 5' in front of the display wall. The monitors sit such that they are at about eye level and approximately 30º left and right of center from the perspective of the seated infant. The camera hole is about 5cm and is well above the monitors. There is an attention getting device (typically a blinking light or display of several small lights) centered between the monitors. Behind the display wall are the monitors, camera, and two VCRs, each of which plays stimuli over one of the TV monitors. The experimenter sits either behind the wall or in a control room. The experimenter controls the stimuli with the VCRs and the attention getting light with a switch or button box. The caregiver wears a visor with a piece of cloth hanging from it so that they cannot see the displays on the monitors and potentially influence the infant's looking behavior. The room is dimly lit, and there are no other stimuli in the room that can distract the infant.

During a word recognition experiment, two words are selected along with two visual displays that correspond to the words. For example, the words *apple* and *flower* would be paired with a picture of an apple and a picture of a flower. Verbs and prepositions can be represented with actors performing actions that correspond to the meanings. At the beginning of each trial, the infant's attention is brought to the center with the attention getting light. In an experimenter-controlled version of the PLP, the experimenter observes the infants via the closed circuit video and monitor system and initiates a test trial only after the infant looks to the center. In another version of the PLP, the stimuli just play out straight through the experiment, and the experimenter simply turns on the attention getting lights for a pre-established amount of time (e.g., 2s) in between presentations of the video and audio stimuli.

During the first trial or two of a PLP experiment, infants are presented with both video displays without auditory stimuli in order to get a baseline measure of any bias to look at one display or the other. Following this *saliency phase,* auditory and visual stimuli are presented during the *test phase.* The auditory stimuli are presented via hidden loudspeakers that are either centered or equidistant left and right of the infants. Both visual displays are presented during each test trial after the infants are centered with the attention getting light, but only one word is presented over the loudspeakers. For example, the infants might hear: "Where's the apple? Can you see the apple? Look at the apple. Apple!" when visual displays of both an apple and a flower are presented. The first sentence of the auditory stimuli plays before the visual stimuli begin in order to allow the infants to show an anticipatory response toward the correct side.

The visual objects are always presented on the same sides. Both auditory stimuli are presented several times (about 4 to 8 times each), usually in a random or semi-random order.

Coding of the infants' looking times is computed offline using a VCR and a monitor. A time code must be burnt onto the coding tape either during the testing session while recording the infant or offline. The coder is kept blind to the experimental conditions by muting the volume of the monitor. While coding the videotape, the coder can see when each trial begins and ends by paying attention to the light from the visual stimuli reflecting off of the infants' faces.[3] The coder steps though the trial, frame by frame, and records the looks to the left, right, center, and away. After coding, the data are separated by condition (e.g., *apple* vs. *flower*), and the left and right looks are averaged for each condition. The data can be analyzed several different ways in order to determine if the infants' look more to the correct objects when they are being named. In case infants are more likely to know one object better than the other, researchers often choose to analyze one condition at a time. For example, one might calculate if infants tend to look at the apple more than the flower when *apple* is presented independently of analyzing the reverse case. Often, researchers analyze the looking behavior during the *test phase* and compare it to what was found during the *saliency phase.* Whatever the details of the statistical analyses, the basic idea of the procedure is to see if infants' look more often and longer to one object when it is being named than when the other object is being named – and vice versa.

Recently, Swingley and his colleagues have developed a variant of the PLP to assess infants' speed of word recognition (Swingley, Pinto, & Fernald, 1998). In their procedure, they calculate not only the amount of time infants look toward the "correct" monitor, but also infants' latency to initiate an eye movement toward the correct monitor. This modification allows researchers to explore the time course of lexical retrieval from long-term memory by infants (e.g., Swingley, Pinto, & Fernald, 1999).

The PLP can also be used for word learning with the addition of a *training phase*. The *training phase* is introduced immediately following the *saliency phase*. During the *training phase,* infants are presented with one or more new objects and words. On each trial, only one of the objects (on the left or right side) and a novel word (e.g., *blick*) are presented. For example, infants might see one object on the right side and hear, "Where's the blick? Do you see the blick? Look at the blick. Blick!" After several trials, infants form an association between the visual objects and the spoken words or nonword sound patterns. The *test phase* is the same as in the word recognition design – visual objects that were taught appear together side by side, and, on each trial, only one of the novel words is presented. If the infants can form the correct association, then they will look longer to the direction of an object when they hear its label than when they hear the label of a different object.

The PLP is the most commonly used procedure for investigating spoken word recognition skills and word learning abilities in infants and young children. The procedure has been used successfully with infants ranging in age from 6 months (e.g., Tincoff & Jusczyk, 1999) to 3 years (Naigles, 1998). The attrition rate is also relatively low (about 10-20%).

Variants of the PLP

The Intermodal Preferential Looking Paradigm (IPLP). For some research questions, it is important that the experimenter have an opportunity to interact with the infant during the experimental procedure. For example, if a researcher wants to explore the effects of eye gaze on word learning, then s/he needs to employ a procedure that allows the infant to see where the experimenter is looking during

[3] Alternatively, the experimenter may set up a small light to turn on during each trial of the experiment, which could be placed behind the infants such that it will be recorded by the camera.

the experiment. The IPLP replaces the monitors with a modified Fagan Board. The Fagan Board is a hinged 40 cm x 50 cm flip board that allows the experimenter to Velcro objects to it. The experimenter can flip it back and forth for quick hiding and displaying of the visual stimuli. In the IPLP, the experimenter produces the auditory stimuli using live voice. The first phase of the IPLP is the *exploration phase,* in which the infants are allowed to physically interact with the objects. Next is the *saliency phase*, which is the same as in the PLP – except that the objects are attached by Velcro to the Fagan Board rather than on TV monitors. The next phase is the *labeling phase* – when the experimenter can either look at the object or look away from the object during labeling, depending on the condition. Finally, the *test phase* is identical to the PLP. During this phase, the experimenter hides behind the Fagan board so as to not influence where the infants look.

The Split-Screen PLP. The Split-Screen PLP was developed by Hollich and colleagues in order to facilitate stimuli creation and testing (Hollich, Rocroi, Hirsh-Pasek, & Golinkoff, 1999). In the Split-Screen version of the PLP, a large wide-aspect TV monitor replaces the two individual monitors. Two visual objects appear on different sides of the same monitor rather than on two different monitors. Using a single monitor rather than two separate displays allows for perfect synchronization of the visual stimuli and requires operating only one VCR, rather than two, during testing. The stimuli are made easily by first recording them using a digital camera and then splicing them together using a digital editing program.

Sensitivity to Phonological Regularities

An important aspect of language development is learning language-specific properties. Recent findings suggest that during the first year of life, infants become sensitive to many language-specific properties in the speech signal. For example, 9-month-olds, but not 6-month-olds attend more to lists of words that contain sequences of sounds that are common in the ambient language in their environment than those that are rare or do not occur (Friederici & Wessels, 1993; Jusczyk, Luce, & Charles-Luce, 1994). Findings like these are important for understanding what properties normal-hearing infants are sensitive to during early language development. Infants' sensitivity to regularities in the sound pattern of spoken language reveals not only that they discriminate speech sounds, but that they also encode them into long-term memory and are able to notice common properties. A method that has been extremely helpful in assessing infants' preferences and sensitivities to properties in speech is the Head Turn Preference Procedure.

Head Turn Preference Procedure (HPP). The HPP was first used by Fernald and her colleagues to show that infants prefer infant-directed speech that contains greater pitch peaks and more exaggerated pitch contours than adult-directed speech (Fernald, 1985; Fernald & Kuhl, 1987). In the HPP, the infant is seated on the caregivers' lap in a 3-sided pegboard booth. There is a green light on the front wall and a red light on each of the side walls. A small hole and a video camera are just above the center light. The caregiver and experimenter listen to masking music over headphones so that they cannot influence the outcome of the experiment. The experimenter controls the lights and auditory stimulus, using a button box. The infant's behavior is observed either through holes in the pegboard or in a control room via a closed-circuit video camera and monitor. The experimenter also uses the button box to record the infant's responses online.

In Fernald's version of the HPP, the infant first completes a short training phase in which s/he is presented with one stimulus type at a time on alternating trials. Each stimulus is paired with one of the two blinking lights on the sides. At the beginning of each trial during the test phase, the infant's attention is first brought to the center by the center green blinking light. When the infant looks to the center-light, the light is extinguished and the red side-lights begin blinking. When the infant looks 30º towards one of the lights, the corresponding stimulus type is presented from behind the light. A preference is indicated if, on average, infants orient significantly more often to one sound pattern than the other.

Recently, Jusczyk and colleagues have used a modified version of the HPP to explore infants' sensitivity to a number of different properties (Jusczyk, 1997; Kemler Nelson et al., 1995). In order to avoid potential side biases, the HPP was modified such that the training period was eliminated and the stimuli were presented randomly to either the left or right side for each trial. Rather than measuring which side the infant orients to, the experimenter measured the average duration of orientation to each stimulus type. At the beginning of each trial, the center-light blinks until the infant looks at it. When the infant is oriented to the center, the experimenter pushes a button on the button box that extinguishes that light and causes one of the side-lights to begin blinking. When the infant orients to the blinking light, the experimenter bushes another button and speech stimuli play from a loudspeaker hidden behind the blinking light. The experimenter responds with button presses each time the infant looks either toward or away from the blinking light. The blinking light and speech continue to play until the infant looks away for two seconds, up to a maximum trial length of about 30 seconds. When the infant orients away from a blinking light but returns within two seconds, the stimuli continue. The amount of time the infant orients to the blinking light is summed for each trial automatically by a computer connected to the button box. For example, in one investigation, Jusczyk, Cutler, and Redanz (1993) showed that 9-month-old English-learning infants orient longer, on average, to lists of words (e.g., *doctor, pliant,* etc.) that follow the predominant stress pattern of English words (i.e., strong/weak) than to lists of words (e.g., *guitar, deride,* etc.) that have the opposite stress pattern (i.e., weak/strong).

Other versions of the HPP have been developed to explore issues of word segmentation and other aspects of language development during the first two years of life (Jusczyk, 1997). In one study, Jusczyk & Aslin (1995) explored infants' ability to recognize the sound pattern of words in sentences. They first familiarized infants with two words by repeating them, one at a time, in citation form. Then they presented sentences, some of which contained the familiarized words and others that contained unfamiliarized target words. By eight months of age, infants attend significantly longer to passages containing familiarized words than to passages containing unfamiliarized target words (Jusczyk & Aslin, 1995). The HPP has also been used to show that infants can recognize familiarized words after delays of one day and longer (Houston & Jusczyk, 2001; Jusczyk & Hohne, 1997). Hence, the HPP is an important methodology that can be used to explore infants' ability to encode speech information into long-term memory. The HPP is successful at exploring the phonological knowledge infants accumulate from exposure to their ambient language (e.g., Jusczyk et al., 1993) as well as testing what phonological information infants can encode during an experiment (e.g., Jusczyk & Aslin, 1995). The procedure has been used successfully with infants from 4.5 months to 2 years, and the attrition rate is about average for infant speech perception measures (approximately 25%).

Current Project

We are now developing an infant speech perception facility in the DeVault Otologic Research Lab in the Riley Children's Hospital ENT clinic. The primary focus of this lab is to make comparisons of speech perception skills of normal-hearing infants and hearing-impaired infants – primarily those who use cochlear implants but also those who use hearing aids for amplification. Very little is currently known about the speech perception skills of hearing-impaired infants, and it is likely that their skills are very limited. Thus, we begin by using the VH and the split-screen PLP to test basic speech perception skills. In the first experiment, we will test infants' ability to discriminate basic speech patterns: a continuous "ahhhh" sound versus a discontinuous "hop hop hop" and rising /i/ versus falling /i/. After the methodologies have proven successful for showing that infants can make these very basic discriminations, we will explore other speech perception and language skills, such as more subtle phonetic distinctions (e.g., /i/ vs. /u/ and /S/ vs. /m/) and novel word learning.

Issues to be Addressed

Infants' Speech Perception and Language Skills. As described earlier, the VH and the PLP are ideally suited for investigating infant speech perception and language skills. The VH is probably the cognitively simpler of the two procedures. It is designed to measure infants' basic response to a change in auditory information – a startle response or a peak of interest that is shown by increased looking duration. For infants to show learning in the PLP, they must first make associations between the auditory and visual stimuli that are presented to them during the training phase. Infants must discriminate auditory stimuli and then, during the test phase, identify which auditory stimulus they hear in order to match it to the correct visual display in front of them. By using both the VH and the PLP, we hope to be able to measure normal-hearing and hearing-impaired infants' basic auditory discrimination abilities and, hopefully, also their ability to make auditory/visual associations that appear to be important for early word learning.

Validity of the Procedures for Hearing-Impaired Infants. The VH and PLP have never been used before to assess speech perception and language skills of hearing-impaired infants. Also, normal-hearing infants' abilities to discriminate gross pattern differences have not been explored with these procedures. Thus, it will be necessary to assess the validity of the procedures using both normal-hearing and hearing-impaired infants. It has been shown repeatedly over the years that normal-hearing infants can discriminate many subtle phonetic differences (e.g., Best et al., 1988), so it goes without question that they could discriminate gross phonetic-acoustic differences also. By using the VH and PLP to test normal-hearing infants' ability to discriminate "hop hop hop" from "ahhh" and rising /i/ from falling /i/ we will be able to demonstrate that both of these procedures are valid measures of these specific speech perception abilities.

Individual Differences. Another goal in developing new procedures for use in a clinical population is to be able to assess the abilities of individual infants so that speech perception skills can be tracked over time. Research in infant speech perception has been cross-sectional in design, and, as a result, the VH and PLP have not been used to investigate individual infants. In order to evaluate the VH and PLP as possible tools for clinical assessment of speech perception and language abilities in individual infants, both normal-hearing and hearing-impaired infants will be tested repeatedly using the same stimuli, each time they come in for their follow-up clinical appointments (i.e., at 1-month-intervals). If these new procedures are able to measure individual abilities, then we expect to see some consistency in performance over repeated measurements of the same infants.

Inter-Procedure Validity. It is possible that one of the procedures will be useful for testing speech pattern discrimination with normal-hearing and/or hearing-impaired infants, but that the other procedure will not provide a valid measure. To test this possibility the discriminations tested with the two procedures will be switched each month. For example, some infants will be tested on "hop hop hop" versus "ahhh" using the VH and rising /i/ versus falling /i/ using the PLP in one session. And then the next month, they would be tested on "hop hop hop" versus "ahhh" using the PLP and rising /i/ versus falling /i/ using the VH. Thus, both procedures will be used to test both discriminations of all the infants. By taking this approach, the procedures can be used to demonstrate the validity of the methodology. If normal-hearing and/or hearing-impaired infants can demonstrate the ability to make a particular discrimination using one procedure, then we would expect them to show a similar pattern with the other procedure. A pattern of results showing that infants could make a particular discrimination with one procedure but not a second procedure would suggest that the second procedure is not sensitive enough to infants' speech discrimination skills.

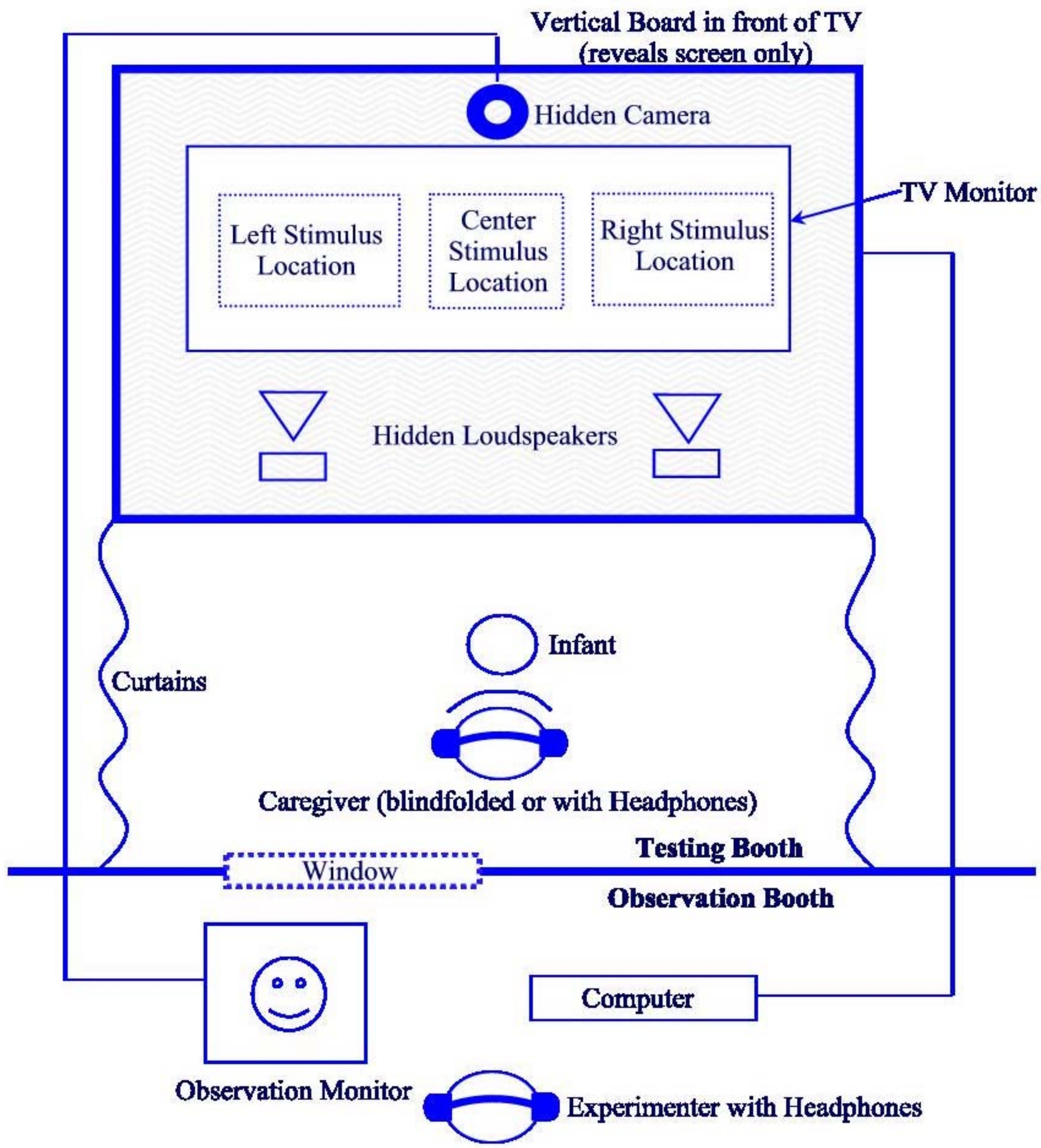

Figure 1. Set up for Preferential Looking Paradigm (PLP) and Visual Habituation (VH) Procedure. During PLP, the caregiver wears a visor as a blindfold, while during the VH, the caregiver wears headphones playing masking music. The Center Stimulus Location is where all the visual stimuli appear during VH and where the graphic of the infant appears in both procedures. The Right and Left Stimulus Locations is where the visual stimuli appear for the PLP only.

Set Up

The VH and PLP will be conducted in a single, soundproof room using the same equipment (see Figure 1). In both procedures, the infant will be seated on the caregiver's lap in front of a 55" wide-aspect monitor. A flat 6-1/2' X 6' wooden structure that is painted black sits in front of the television, revealing only the monitor of the television so that the infant has nothing else to look at in front. Also, curtains hang from ceiling to floor to the left and right of the infant to prevent distraction by any other objects in the room. The experimenter controls the experiments from a control room adjacent to the soundproof booth. A camera records the infant through a hole in the wooden structure and displays the image onto a monitor in the control room. The experimenter wears headphones playing masking music during both procedures. The caregiver does the same during the VH but wears a visor instead during the PLP, so s/he cannot see which side visual stimuli are presented. During each session, the infant will be tested on his/her ability to discriminate one pair of stimuli ("hop hop hop" vs. "ahhh" or rising /i/ vs. falling /i/) using the VH and the other pair using the PLP. Both procedures will be implemented using Habit software (Cohen, Atkinson, & Chaput, 2000) on a Macintosh G4.

Procedure (VH). The procedure of the VH will be as follows. At the beginning of each trial, a graphic of an infant will appear at the center of the monitor. When the infant looks to the center, the experimenter will push a key on the keyboard, which will extinguish the center attractor and initiate the visual and auditory stimuli. A red and white checkerboard pattern will appear in the center of the monitor, and the infant will hear one of the stimulus items repeat. When the infant looks away, the experimenter will push another key, which will end the trial and begin the next trial. The trials will continue until the average orientation duration of three sequential looks is less than 50% of the average of the initial three looks. The test phase consists of two trials. The 'same' trials are identical to the trials during the habituation phase. The 'switch' trial consists of a novel auditory stimulus with the same visual display. The order of the 'same' and 'switch' trials will be counterbalanced across infants and within infants across sessions.

Procedure (PLP). The visual stimuli used in the PLP will be physically correlated to the speech stimuli. "Hop hop hop" will be paired with video of a toy kangaroo hopping. "Ahhh" will be paired with a video of a toy airplane moving from left to right across the screen. Rising /i/ will be paired with a video of white bubble rising up in a lava lamp. Falling /i/ will be paired with a video of a ball rolling down a plastic spiral ramp. The auditory and visual stimuli will be digitized onto the Macintosh G4, and EditDV™ will be used to create the visual "split-screen" effects and to synchronize the audio and visual stimuli. As with the VH, each trial will begin with a graphic of an infant on the center of the screen as an attention getter, and the test stimuli will be presented once the infant looks to the center. The procedure will consist of: *Saliency Phase* – one trial with both visual stimuli and no auditory stimuli; *Training Phase 1* – eight trials where the two visual/auditory stimulus pairs will be presented one at a time, the first half in alternating order and the second half in random order; *Test Phase 1* – six trials in random order where both visual stimuli are on the screen but only one auditory stimulus is presented; *Training Phase 2* – six more training trials of the same stimuli in random order; and *Test Phase 2* – six more test trials of the same stimuli in random order. The looks of the infants will be coded online by the experimenter but then will be double-checked for reliability by using the videotape that will record the infants during testing.

Clinical and Theoretical Significance

The VH and split-screen PLP methodology that is being developed in this project has important clinical and theoretical significance. From a clinical standpoint, at the present time it is absolutely essential that new behavioral techniques be developed that can be used to assess the benefit of implanting infants with CIs at very young ages. At this time, it is not known if providing CIs at increasingly younger ages will actually provide additional outcome benefits and help promote spoken language development in this population. With new measures of speech perception and novel word learning performance, clinicians will be able to assess the development of speech perception abilities of infant CI users and, as a result, they will become better able to make more informed decisions about the age at which infants should undergo CI surgery. Being able to track the progress of individual CI users will also allow clinicians to determine when additional interventions may be necessary to improve outcome performance and help these children reach optimal levels of performance with their CIs.

Finally, from a theoretical perspective, it is of interest to compare language development of normally hearing infants to infants who are first deprived of auditory input and then receive it at a later age via a CI. Do these children follow the same developmental course as normal-hearing infants, even though their early auditory experience was radically different? Also, how does the initial absence of auditory information affect an infants' ability to acquire spoken language? Some language development researchers have hypothesized that there is a "sensitive period" in which the capacity to learn languages declines because of decreasing neural plasticity (e.g., Lenneberg, 1967; Newport, 1990). These important theoretical issues in neural and behavioral development can be explored for the first time in a pediatric population by investigating the language development of hearing-impaired infants who are deprived of auditory input during the early part of the sensitive period and then receive a CI. However, this unique research opportunity may be lost without appropriate behavioral techniques that can measure and track the changes in their perceptual skills over time after implantation. Adapting novel techniques like the PLP for use with the young CI population will allow us an unusual opportunity to investigate and measure the effects of early sensory deprivation on speech perception and spoken language acquisition and help us to understand the behavioral and neural basis for the large differences in outcome performance of CI users.

References

American Academy of Pediatrics Task Force on Newborn and Infant Hearing (1999). Newborn and infant hearing loss: Detection and intervention. *Pediatrics, 103*, 527-530.

Best, C.T., McRoberts, G.W., & Sithole, N.M. (1988). Examination of the perceptual re-organization for speech contrasts: Zulu click discrimination by English-speaking adults and infants. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 345-360.

Cohen, L.B. (1969). Observing responses, visual preferences, and habituation to visual stimuli in infants. *Journal of Experimental Child Psychology, 7*, 419-433.

Cohen, L.B., Atkinson, D.J., & Chaput, H.H. (2000). Habit 2000: A new program for testing infant perception and cognition. (Version 1.0). Austin: the University of Texas.

Dorman, M.F., Hannley, M.T., Dankowski, K., Smith, L., & McCandless, G. (1989). Word recognition by 50 patients fitted with the Symbion multichannel cochlear implant. *Ear & Hearing, 10*, 44-49.

Eimas, P.D., Siqueland, E.R., Jusczyk, P., & Vigorito, J. (1971). Speech perception in infants. *Science, 171*, 303-306.

Fenson, L., Dale, P., Reznick, S., Bates, E., Thal, D., & Pethick, S. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development, 59* (Serial number 242).

Fernald, A. (1985). Four-month-old infants prefer to listen to motherese. *Infant Behavior and Development, 8*, 181-195.

Fernald, A., & Kuhl, P.K. (1987). Acoustic determinants of infant preference for motherese speech. *Infant Behavior and Development, 10*, 279-293.

Friederici, A.D., & Wessels, J.M.I. (1993). Phonotactic knowledge and its use in infant speech perception. *Perception & Psychophysics, 54*, 287-295.

Geers, A.E. (1994). Techniques for assessing auditory speech perception and lipreading enhancement in young deaf children. In A. E. Geers & J. S. Moog (Eds.), *Effectiveness of cochlear implants and tactile aids for deaf children: The sensory aids study at central institute for the deaf.* (pp. 85-96). Washington, D.C.: Alexander Graham Bell Association for the Deaf.

Geers, A.E., & Moog, J.S. (1989). Evaluating speech perception skills: Tools for measuring benefits of cochlear implants, tactile aids, and hearing aids. In E. Owens & D.K. Kessler (Eds.), *Cochlear implants in young deaf children*. Boston: College-Hill Press.

Golinkoff, R., Hirsh-Pasek, K., Cauley, K., & Gordon, L. (1987). The eyes have it: Lexical and syntactic comprehension in a new paradigm. *Journal of Child Language, 14*, 23-45.

Gravel, J.S. (1997). Behavioral audiologic testing. In A. Lalwani & K. Grundfast (Eds.), *Pediatric otology and neurotology*. Philadelphia: J. B. Lippincott.

Hayes, D., & Northern, J.L. (1996). *Infants and hearing*. San Diego, CA: Singular.

Hollich, G., Rocroi, C., Hirsh-Pasek, K., & Golinkoff, R. (1999). *Testing language comprehension in infants: Introducing the split-screen preferential looking paradigm.* Paper presented at the Society for Research in Child Development Biennial Meeting, Albuquerque, NM.

Horowitz, F.D. (1975). Infant attention and discrimination: Methodological and substantive issues. *Monographs of the Society for Research in Child Development, 39* (Serial no. 158).

Houston, D.M., & Jusczyk, P.W. (2001). *Infants' long-term memory for words and voices*. Manuscript submitted for publication.

Joint Committee on Infant Hearing: Year 2000 position statement (2000). Principles and guidelines for early hearing detection and intervention programs. *American Journal of Audiology, 9*, 9-29.

Jusczyk, P.W. (1997). *The discovery of spoken language*. Cambridge, MA: MIT Press.

Jusczyk, P.W., & Aslin, R.N. (1995). Infants' detection of the sound patterns of words in fluent speech. *Cognitive Psychology, 29*, 1-23.

Jusczyk, P.W., Cutler, A., & Redanz, N.J. (1993). Infants' preference for the predominant stress patterns of English words. *Child Development, 64*, 675-687.

Jusczyk, P.W., & Hohne, E.A. (1997). Infants' memory for spoken words. *Science, 277*, 1984-1986.

Jusczyk, P.W., Luce, P.A., & Charles-Luce, J. (1994). Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory & Language, 33*, 630-645.

Kagan, J., & Moss, M. (1965). Studies of attention in the human infant. *Merril-Palmer Quarterly, 11*, 95-127.

Kemler Nelson, D.G., Jusczyk, P.W., Mandel, D.R., Myers, J., Turk, A., & Gerken, L.A. (1995). The Headturn Preference Procedure for testing auditory perception. *Infant Behavior & Development, 18*, 111-116.

Kirk, K.I., Diefendorf, A.O., Pisoni, D.B., & Robbins, A.M. (1997). Assessing speech perception in children. In L. Mendel & J. Danhauser (Eds.), *Audiological Evaluation and Management and Speech Perception Training* (pp. 101-132). San Diego: Singular Publishing Group.

Kuhl, P.K. (1979). Speech perception in early infancy: Perceptual constancy for spectrally dissimilar vowel categories. *Journal of the Acoustical Society of America, 66*, 1668-1679.

Lenneberg, E. (1967). *Biological foundations of language*. New York: Wiley.

Mandel, D.R., Jusczyk, P.W., & Pisoni, D.B. (1995). Infants' recognition of the sound patterns of their own names. *Psychological Science, 6*, 315-318.

Mehler, J., Jusczyk, P., Lambertz, G., Halsted, N., Bertoncini, J., & Amiel-Tison, C. (1988). A precursor of language acquisition in young infants. *Cognition, 29*, 143-178.

Miyamoto, R.T., Kirk, K.I., Robbins, A.M., Todd, S.L., & Riley, A.I. (1996). Speech perception and speech production skills of children with multichannel cochlear implants. *Acta Oto-Laryngologica, 116*, 240-243.

Moore, J.M., Thompson, G., & Thompson, M. (1975). Auditory localization of infants as a function of reinforcement conditions. *Journal of Speech and Hearing Disorders, 40*, 29-34.

Naigles, L.R. (1998). Developmental changes in the use of structure in verb learning: Evidence from preferential looking. In C. Rovee-Collier, L. P. Lipsitt & H. Hayne (Eds.), *Advances in infancy research* (Vol. 12, pp. 298-318). Stamford, CT: Ablex.

Nazzi, T., Bertoncini, J., & Mehler, J. (1998). Language discrimination by newborns: toward an understanding of the role of rhythm. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 756-766.

Newport, E. (1990). Maturational constraints on language learning. *Cognitive Science, 14*, 11-28.

Northern, J.L., & Downs, M. P. (1991). *Hearing in children*. Baltimore: Williams & Wilkins.

Polka, L., & Werker, J.F. (1994). Developmental changes in perception of non-native vowel contrasts. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 421-435.

Primus, M. (1992). The role of localization in visual reinforcement audiometry. *Journal of Speech and Hearing Research, 35*, 1137-1141.

Siqueland, E.R., & DeLucia, C.A. (1969). Visual reinforcement of non-nutritive sucking in human infants. *Science, 165*, 1144-1146.

Stager, C.L., & Werker, J.F. (1997). Infants listen for more phonetic detail in speech perception than in word-learning tasks. *Nature, 388*, 381-382.

Swingley, D., Pinto, J.P., & Fernald, A. (1998). Assessing the speed and accuracy of word recognition in infants. In C. Rovee-Collier, L.P. Lipsitt & H. Hayne (Eds.), *Advances in Infancy Research* (Vol. 12, pp. 257-277). Stamford, CT: Ablex.

Swingley, D., Pinto, J.P., & Fernald, A. (1999). Continuous processing in word recognition at 24 months. *Cognition, 71*, 73-108.

Thomas, D.G., Campos, J.J., Shucard, D.W., Ramsay, D.S., & Shucard, J. (1981). Semantic comprehension in infancy: A signal detection analysis. *Child Development, 52*, 798-803.

Thompson, G., & Folsom, R.C. (1984). A comparison of two conditioning procedures in the use of visual reinforcement audiometry (VRA). *Journal of Speech and Hearing Disorders, 49*, 241-245.

Tincoff, R., & Jusczyk, P.W. (1999). Some beginnings of word comprehension in 6-month-olds. *Psychological Science, 10*, 172-175.

Watrous, B. S., McConnell, F., Sitton, A. B., & Fleet, W. F. (1975). Auditory responses of infants. *Journal of Speech and Hearing Disorders, 40*, 357-366.

Werker, J.F., Cohen, L.B., Lloyd, V.L., Casasola, M., & Stager, C.L. (1998a). Acquisition of word-object associations by 14-month-old infants. *Developmental Psychology*.

Werker, J.F., Shi, R., Desjardins, R., Pegg, J.E., Polka, L., & Patterson, M. (1998b). Three methods for testing infant speech perception. In A. Slater (Ed.), *Perceptual development: Visual, auditory, and speech perception in infancy.* East Sussex, UK: Psychology Press.