2006

Relational learning in children with cochlear implants

Wagner R. da Silva
Universidade Federal de Sao Carlos

Et al.

Repository Citation

da Silva WR, de Souza Dd, de Rose JC, Lopes J, Bevilacqua MC, McIlvane WJ. (2006). Relational learning in children with cochlear implants. Eunice Kennedy Shriver Center Publications. Retrieved from https://escholarship.umassmed.edu/shriver_pp/26

EXPERIMENTAL ANALYSIS OF HUMAN BEHAVIOR BULLETIN 2006, **24,** 1-8

BRIEF REPORT

RELATIONAL LEARNING IN CHILDREN WITH COCHLEAR IMPLANTS

Wagner R. da Silva, Deisy das Graças de Souza, Julio C. de Rose

UNIVERSIDADE FEDERAL DE SÃO CARLOS

Jair Lopes Jr.

UNIVERSIDADE ESTADUAL PAULISTA

Maria Cecília Bevilacqua

UNIVERSIDADE DE SÃO PAULO

William J. McIlvane

UNIVERSITY OF MASSACHUSETTS MEDICAL SCHOOL

A cochlear implant is a prosthesis that substitutes for Corti's organ and stimulates electrically the ganglion cells and nerve fibers of the auditory nerve, enabling auditory stimulation. External components of the device comprise a microphone (usually placed behind the ear) that receives external sounds and transmits them, via cable, to a speech processor (roughly the size of a cellular phone). The processor analyzes the sound and digitizes it into coded signals that are sent, through a transmitting coil, as radio-frequency signals (FM) to the cochlear implant receiver/stimulator under the skin. Surgically implanted electrodes placed along the cochlea are connected to the receiver/stimulator through a cable of platinum-iridium wires. The receiver/stimulator delivers the appropriate amount of electrical energy to the electrodes, stimulating the remaining auditory nerve fibers in the cochlea. This electrical sound information is sent from the auditory nerve fibers through the auditory system to the brain, resulting in auditory sensation (Clark, 1997, 2003; Waltzman & Cohen, 2000).

Several studies demonstrate that cochlear implant users show successful development of auditory comprehension and speech (e.g., Löhle et al., 1999; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). Bevilacqua, Costa and Moret (2003) studied 63 deaf children with cochlear implants and found that 45% of individuals who became deaf prelingually (i.e., before acquiring language) achieved high auditory abilities; auditory abilities were rated as intermediate for 38% and low for 17%. Regarding oral language, 62% produced simple and complex phrases, whereas 38% produced only isolated words or no language at all. Longitudinal studies (e.g., Gstoettner, Hamzavi, Egelieder, & Baumgartner, 2000) showed increasing improvements in speech comprehension and speech intelligibility in prelingually deaf users of cochlear implant over the first 6 to 18 months after implant activation. However, their performances still lag behind the linguistic repertoire of typically developing children. Asymptotic performances have been observed around five years after implant activation (Hansel, Engelke, Otenjann, & Westhofen, 2005).

Bevilacqua et al. (2003) argue that critical factors for implant success, particularly with prelingually deaf children, are (a) early

---

This article is based on a thesis submitted by W. R. da Silva in partial fulfillment of requirements for a Master's degree in the Graduate Program in special education, Universidade Federal de São Carlos. The research was supported by Grant #463088/2000-0 and fellowships from Conselho Nacional de Desenvolvimento Científico e Tecnológico (Brazilian Research Council). Manuscript preparation was supported by FAPESP Grant 03/09928-4 and NICHD Grant No. HD 39816. We thank Flávia M. L. Rizzi, Liège F. Tanamate, Patrícia D. Campos, and Raquel Golfeto for assistance with data collection. We also thank Ana Claudia Almeida-Verdu for input on previous versions of this manuscript.

implantation, (b) precise speech processor adjustments, and (c) the quality of auditory habilitation (for the prelingually deaf) or rehabilitation (for the postlingually deaf).

A major component of (re)habilitation is training to establish symbolic functions for auditory stimuli. To monitor results of training, it is necessary to assess symbolic function of auditory stimuli received through the implant. However, as Sidman and Tailby (1982) pointed out, symbolic relations between stimuli are not overtly distinguishable from conditional relations of questionable symbolic status. They argued that symbolic relations are equivalence relations between stimuli, defined mathematically by the properties of reflexivity, symmetry, and transitivity. Sidman and Tailby (1982) established conditional relations involving auditory and visual stimuli and then tested for emergent relations that documented the defining properties of equivalence. These tests have become standard practice in the assessment of equivalence classes.

Extensive research with both normally capable individuals and individuals with various types of disabilities has documented the applicability of the method to virtually every conceivable type of symbolic relations. These include all-visual relations (e.g., Spradlin, Cotter & Baxley, 1973), all-auditory relations (Dube, Green & Serna, 1993), tactile-visual relations (Bush, 1993), gustatory-visual relations (Hayes, Tilley, & Hayes, 1998), proprioceptive-visual relations (DeGrandpre, Bickel, & Higgins, 1992), as well as (most pertinent to the present work), auditory-visual relations (e.g., de Rose, de Souza, & Hanna, 1996; Green, 1990; Sidman & Tailby, 1982).

Stimulus equivalence has been studied with deaf children and others with language impairments. Variable outcomes have been reported: negative results (Devany, Hayes, & Nelson, 1986), mixed results (Barnes, McCullag, & Keenan, 1990; Vause, Martin, Yu, Marion, & Sakko, 2005), or mostly positive results (Carr, Wilkinson, Blackman, & McIlvane, 2000). These results suggest that training procedures to establish stimulus relations with these populations may vary in their symbolic outcomes. The present study attempted to extend the stimulus equivalence methodology to study auditory-visual relations and assess their symbolic function in individuals with profound bilateral sensorineural hearing loss who had received cochlear implants.

METHOD

Participants

Participants were two children and two teenagers. Each had received a Nucleus 22® cochlear implant 2-4 years before. Table 1 presents their hearing loss etiology and other characteristics. The children were prelingually deaf and teenagers were postlingually deaf. At the beginning of the study the children could distinguish between words on the basis of their consonants and could produce two-word or three-word phrases, thus demonstrating that they could respond, to some degree, to stimuli delivered by the speech processor. Also, they were proficient at lip reading, but did not use sign language and were doing poorly at school, exhibiting very limited reading repertoires. The teenagers acquired language before becoming deaf and language functions completely recovered during the first six months after the implant's activation.

Setting, Stimuli, and Apparatus

Experimental sessions were conducted during a three-day hospital visit for implant maintenance. Sessions were scheduled at any available time during routines for implant fitting and conducted in a room (7 x 4 m) containing two workstations, located facing two adjacent walls of the room and separated visually by cabinets. The experimental session was conducted in one of the stations while the other could be in use for implant fitting with another patient. Participants had the speech processor turned off during sessions, eliminating competing auditory stimulation. Sessions were 20 to 30 minutes long. Two to four sessions could be conducted daily.

Three sets of visual stimuli and one set of auditory stimuli were presented in a matching-to-sample format. All sets contained three stimuli each. Visual stimuli were Greek letters (Set A = Λ, Ω, Γ; Set B = Ξ, Σ, Π; Set C = ω, λ, δ), approximately 3 cm high (font Arial 120). Visual stimuli were displayed on a 14-in computer monitor. The display consisted of white windows (4 x 4 cm) on a gray background. One window was located on the center and one in each of the four corners. The attached computer controlled all experimental operations, except for auditory stimulus generation. Auditory stimuli were presented by another computer, interfaced with the implant. The Nucleus 22® has 22 electrodes implanted along the cochlea. Auditory stimuli (Set

Table 1

Participants' characteristics.

Participants	Gender	Age (yrs)	Time since Implant (yrs)	Duration of auditory deprivation (yrs)	Type of deafness	Acquisition of deafness
RFL	M	16	2	1	Acquired	Postlingually
RNT	F	12	4	1	Acquired	Postlingually
SBL	F	8	3	5	Acquired	Prelingually
CML	F	8	4	4	Congenital	Prelingually

Note. All four participants had received Nucleus 22® cochlear implants.

D) were electrical signals (a sequence of five 1-s discrete pulses) delivered to single electrodes in three different cochlear positions: basal, medial, and apical. As a result of these placements, D1, D2, and D3 were heard as high-, medium-, and low-pitched tones, respectively. Table 2 shows locations and resulting frequencies.

Procedure

The experiment had two phases. In Phase I, visual-visual AB and AC arbitrary matching relations were taught directly, thus providing the logical basis for the emergence of BC and CB relations (i.e., combined tests for symmetry and transitivity [Sidman & Tailby, 1982]). Arbitrary stimulus relations were used to ensure that any emergent stimulus equivalence relations were due to the experimental procedures and not to prior learning. In Phase II, arbitrary auditory-visual matching relations (DC) were introduced. The goal was to determine (1) if such relations could be established and (2) if so, whether DA and DB relations would emerge, thus demonstrating the expansion of the equivalence classes. The experiment was presented as a game in which the participant was instructed to try to be correct as much as possible. Correct selections produced a picture of a hand making a "thumbs up" signal, displayed on the screen for approximately 2-s; a 2-s dark screen followed incorrect selections. The following trial began immediately after the confirming or disconfirming consequence.

Phase 1. The experimenter modeled responding (two modeling trials for the teenagers and five for children) and then passed the mouse button to the participant. All visual-visual matching-to-sample trials began with a Greek-letter sample stimulus presented in the center window. Participants were required to place the cursor within that square and then to depress the mouse button. If they did not press, the experimenter pointed to the picture and to the mouse button. Immediately after a response, comparison stimuli were displayed simultaneously in any three of the four squares located in the corners of the computer screen. Participants chose a comparison stimulus by placing the cursor within its square and depressing the button once again. If they showed any evidence of not knowing what to do the experimenter used manual guidance, placing his hand over the participant's hand and moving the cursor over the screen. Guidance was necessary only very rarely.

AB relations were trained first. Training was comprised of 16 consecutive blocks of trials. During all baseline training, each block repeated until the participant selected correctly on all trials of the block. Blocks 1 through 5 trained a conditional discrimination with samples A1 and A2, and comparisons B1 and B2. The two initial blocks presented only one sample (A1 in the first and A2 in the second) on all trials of the block, with both comparisons. These blocks had 8 trials each. Blocks 3 and 4 also alternated samples A1 and A2, now with 4 trials in each block. The fifth block, with 6 trials, presented samples A1 and A2 in a randomized sequence. Therefore, blocks 1 through 5 established a conditional discrimination with samples A1 and A2 and comparisons B1 and

Table 2

Electrode locations and frequency band (hertz) of tones used as D stimuli (D1, D2, and D3) for each participant.

	D1		D2		D3	
Participants	Electrode number (Basal)	Frequency Band (Hz)	Electrode number (Medial)	Frequency Band (Hz)	Electrode number (Apical)	Frequency Band (Hz)
RFL	5	4093-5744	14	1350-1550	20	150-350
RNT	5	4093-5744	14	1350-1550	20	150-350
SBL	5	5744-6730	14	1550-1768	19	550-750
CML	5	6730-7885	14	1768-2031	20	550-750

B2, in a minimum of 30 trials. Then, blocks 6 through 10 used a similar sequence to train a conditional discrimination with samples A1 and A3 and comparisons B1 and B3. A similar sequence was used in blocks 11 through 15 to train a conditional discrimination with samples A2 and A3 and comparisons B2 and B3. Finally, block 16 had 18 trials with samples A1, A2, and A3 in a randomized sequence; each trial presented comparisons B1, B2, and B3. Therefore, training the AB conditional discrimination required a minimum of 108 trials (30 for blocks 1 to 5, 30 for blocks 6 to 10, 30 for blocks 11 to 15, and 18 for block 16). After a similar sequence of blocks taught the AC conditional discrimination, participants were instructed that confirming consequences would appear only in some trials, and the next block presented 6 trials, intermixing AB and AC conditional discriminations, with confirming consequences on 50% of the trials.

The following sessions inserted probes for emergent relations BC, and CB. Probe blocks mixed, in a randomized order, 9 AB trials, 9 AC trials, and 9 BC or CB probe trials. Each block tested only one emergent relation and provided confirming consequences only on baseline trials (the overall probability was maintained at 0.5). The next block presented 6 trials reviewing AB baseline. The next probe block mixed 9 BA symmetry probes with 18 AB trials. A block reviewing AC baseline also preceded CA symmetry probes, conducted in a block mixing 9 CA trials with 18 AC trials.

Usually two blocks were conducted for BC and CB equivalence probes and one block for BA and CA symmetry probes. For CML, symmetry probes were omitted due to the limited time available for sessions. Participant RNT showed low scores in BC and CB probes together with a steady decrease in baseline scores (see Results, below). Equivalence probes were then discontinued for this participant and the next two blocks reviewed the AB baseline, with confirming consequences in 50% of the trials. Two blocks of BA symmetry probes followed. BC probes resumed, followed by CA symmetry probes and then CB probes.

Phase 2. DC relations were established between auditory samples (D1, D2, D3) and visual comparisons (C1, C2, C3), using a sequence of blocks similar to that used to train AB and AC (with a minimum of 108 trials). The participant was told that the speech processor would be disconnected, and that he or she should make a hand signal when an auditory stimulus was presented. Participants were familiar with this practice, often used during the clinical procedures. At the start of each trial, visual comparison stimuli were displayed simultaneously with the five-pulse sequence and the experimenter held the mouse until the participant indicated that he or she detected a sound. If no response occurred within 10 s, another sequence was presented, and this was repeated until the participant raised his or her hand. Then, he or she was given the mouse. Confirming or disconfirming consequences followed the selection of a comparison stimulus. Thereafter, AB and AC trial types were reintroduced and intermixed with DC trials. Training blocks had 9 trials, reinforcement probability was reduced to 0.5 and blocks repeated until 100% of selections were correct.

Phase 2 established the basis for the emergence of DA and DB auditory-visual conditional relations, thus serving as a combined test for symmetry and transitivity. Each of these relations was evaluated in a separate 36-trial test block (nine of each baseline relation, AB, AC, and DC, and nine probe trials: DA or DB). Reinforcement probability was 0.50 for baseline trials, and no confirming consequences followed probe trials.

RESULTS AND DISCUSSION

RFL completed Phase 1 with the minimum number of trials required: 216. RNT and CML needed 224 trials to complete this Phase, and SBL needed 236 trials. In Phase 2, participants RFL and RNT (postlingually deaf) required 112 and 148 trials to complete training, respectively. Participants CML and SBL (prelingually deaf) completed only the blocks of Phase 2 with one sample but never achieved criterion in the first block that presented two samples.

Figure 1 shows accuracy scores of all participants in equivalence tests in Phases 1 and 2. Each bar corresponds to one block of test trials. Connected squares represent scores on baseline trials in probe blocks. Participants' initials and ages are shown to the right of the data. All participants exhibited stimulus equivalence with visual stimuli A, B, and C. CML showed high scores in equivalence probes from the beginning and the other participants showed somewhat delayed emergence of equivalence. RNT, particularly, showed low scores in equivalence probes and also a decrease in baseline scores. Equivalence emerged only after retraining of AB baseline and BA symmetry tests. Deafness, therefore, did not interfere with development of symbolic relations per se.

In Phase 2, RFL, one of the two participants who learned the DC auditory-visual conditional discrimination, also showed auditory-visual equivalence classes. RNT, the other participant tested for auditory-visual classes, showed increasing scores in the two initial DA probe blocks, reaching about 75% of selections consistent with auditory-visual equivalences in the second block. She then showed 100% selections consistent with equivalence in the next probe block, which tested the DB relation. Subsequent probe blocks showed deterioration of the DB relation and of baseline performance as well. No consistent pattern was found in the inconsistent selections. It is possible that baseline retraining, followed by retesting of equivalence, could promote the emergence of the auditory-visual classes for RNT. No further time was available, however, to continue the study with this participant.

Successful matching to sample requires a simultaneous discrimination between the comparison stimuli and a successive discrimination between the samples. Participants had already proved capable of acquiring the simultaneous and successive discriminations between the visual stimuli in Phase 1. The Phase-2 auditory samples, however, were pure tones. These stimuli were detected by all participants, but CML and SBL did not achieve criterion when discriminations between them were required. Perhaps these difficulties were due to the nature of the stimuli. Discrimination of pure tones in isolation may be an unusually challenging auditory task – perhaps even for people whose hearing is unimpaired. Notably, all participants could discriminate certain more complex auditory stimuli (dictated words) presented via the speech processor after 2-4 years of post-implant training.

A question for future research is whether the learning failures exhibited by some participants in this study can be overcome by using different auditory stimuli. Training in this study was constrained by practical realities of the hospital situation (only a 3-day stay, competition from clinical appointments, etc.). It seems reasonable to suppose that more familiar auditory stimulus types (e.g., dictated words rather than pure tones) would speed acquisition – although this is by no means certain. Also better programming of procedures for teaching auditory-visual matching might have facilitated learning the equivalence relations.

Certain limitations notwithstanding, this study does point to a population that may be of great interest within the experimental analysis of human behavior. In contrast with the other participants, RFL successfully acquired auditory-visual matching and also showed class expansion with inclusion of the auditory stimuli. Thus, studying auditory-visual stimulus equivalence in users of cochlear implants is feasible. For those concerned with foundations of relational learning (e.g., Hayes, 1991; McIlvane, Serna, Dube, & Stromer, 2000), the deaf population – especially the young, prelingually deaf – stands out as

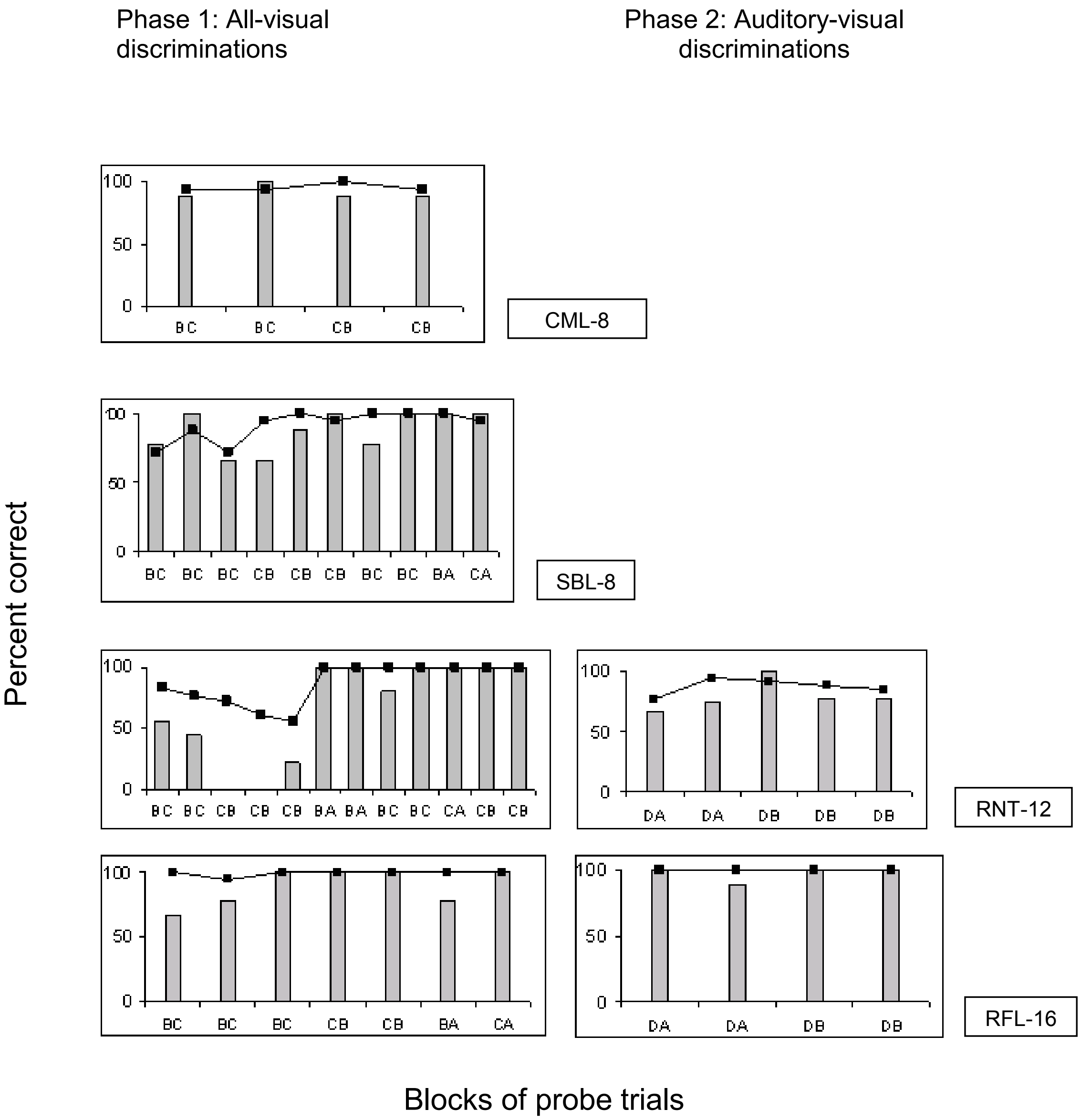

Figure 1

potentially attractive test case. Most such children may be presumed to have little or no central neurological damage/dysfunction. Their sensory limitations are often due to peripheral impairments (e.g., those resulting from infections) and, more importantly, these limitations may be partially or fully correctable via increasingly capable cochlear implants. It might be possible, therefore, to study the conditions under which the newly received auditory stimuli are related to stimuli from other modalities. One might, for example, assess the degree to which multiple exemplar training is necessary to establish relational learning performances involving auditory stimuli.

For scientists and clinicians interested in assessing and/or remediating sensory disorders (e.g., audiology, speech pathology, etc.), the equivalence paradigm offers easily implemented methodology for assessing symbolic functions. The equivalence tests are well-operationalized and have substantial face validity (Wilkinson & McIlvane, 2001). If children can acquire the requisite matching-to-sample baselines, the consequence is highly likely to be emergent behavior that confirms symbolic status (McIlvane et al., 2000; Sidman, 1994). Such circumstances thus provide a secure basis for comparison when exploring largely uncharted territories such as the nature and quality of relations involving cochlear-implant delivered auditory stimuli.

REFERENCES

Barnes, D., McCullag, P. D., & Keenan, M. (1990). Equivalence class formation in non-hearing impaired children and hearing impaired children. *The Analysis of Verbal Behavior, 8,* 19-30.

Bevilacqua, M. C., Costa Filho, O. A., & Moret, A. L. M. (2003). Implante coclear em Crianças [Cochlear implant in children]. In A. H. Campos & O. O. Costa (Eds.). *Tratado de otorrinolaringologia* (pp. 268-277). São Paulo: Roca.

Bush, K. M. (1993). Stimulus equivalence and cross-modal transfer. *Journal of the Experimental Analysis of Behavior, 43,* 567-584.

Carr, D., Wilkinson, K. M., Blackman, D., & McIlvane, W. J. (2000). Equivalence classes in individuals with minimal verbal repertoires. *Journal of the Experimental Analysis of Behavior, 74,* 101-114.

Clark, G. M. (1997). *Cochlear implantation for infants and children - Advances*. San Diego: Singular.

Clark, G. M. (2003). *Cochlear implants. Fundamentals and applications.* New York: Springer Verlag.

DeGrandpre, R. J., Bickel, W. K., & Higgins, S. T. (1992). Emergent equivalence relations between interoceptive (drug) and exteroceptive (visual) stimuli. *Journal of the Experimental Analysis of Behavior, 58,* 9-18.

de Rose, J. C., de Souza, D. G., & Hanna, E. S. (1996). Teaching reading and spelling: Exclusion and stimulus equivalence. *Journal of Applied Behavior Analysis, 29,* 451-469.

Devany, J. M. Hayes, S. C., & Nelson, R. O. (1986). Equivalence class formation in language-able and language-disabled children. *Journal of the Experimental Analysis of Behavior, 46,* 243-257.

Dube, W., Green, G., & Serna, R. (1993). Auditory successive conditional discrimination and auditory stimulus equivalence classes. *Journal of the Experimental Analysis of Behavior, 59,* 103-114.

Green, G. (1990). Difference in development of visual and auditory-visual equivalence relations. *American Journal on Mental Retardation, 95,* 260-270.

Gstoettner, W. K., Hamzavi, J., Egelieder, B., & Baumgartner, W. D. (2000). Speech perception performance in prelingually deaf children with cochlear implants. *Acta Otolaryngology, 120,* 209-213.

Hansel, J., Engelke, J. C., Ottenjann, W., & Westhofen, M. (2005). Long term results of cochlear implantation in children. *Otolaryngology – Head and Neck Surgery, 132,* 456-458.

Hayes, S. C. (1991). A relational control theory of stimulus equivalence. In L. J. Hayes & P. N. Chase (Eds.), *Dialogues on verbal behavior* (pp. 19-40). Reno, NV: Context Press.

Hayes, L. J., Tilley, K. J., & Hayes, S. C. (1998). Extending equivalence class membership to gustatory stimuli. *The Psychological Record, 38,* 275 -291.

Löhle, E., Frischmuth, S., Becker, M. H., Flamm, K., Laszig, R., Beck, C., & Lehnhardt, E. (1999). Speech recognition, speech production and speech intelligibility in children with hearing aids versus implanted children. International *Journal of Pediatric Otorhinolaryngology, 47,* 165-169.

McIlvane, W. J., Serna, R., Dube, W., & Stromer, R. (2000). Stimulus control topography coherence and stimulus equivalence: Reconciling test outcomes with theory. In J. Leslie & D. E. Blackman (Eds.). *Issues in experimental and applied analyses of human behavior.* Reno: Context Press.

Sidman, M. (1994). *Equivalence relations and behavior: A research story.* Boston, MA: Authors Cooperative.

Sidman, M., & Tailby, W. (1982). Conditional discrimination vs. matching to sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior, 37,* 5 - 22.

Spradlin, J. E., Cotter, V. W., & Baxley, N. (1973). Establishing a conditional discrimination without direct training: A study of transfer with retarded adolescents. *American Journal of the Mental Deficiency, 77,* 556-566.

Svirsky, M. A., Robbins, A. M., Kirk, K. I., Pisoni, D. B., & Miyamoto, R. T. (2000). Language development in profoundly deaf children with cochlear implants. *Psychological Science, 11,* 153-158.

Vause, T., Martin, G. L., Yu, C. T., Marion, C., & Sakko, G. (2005). Teaching equivalence relations to individuals with minimal verbal repertoires: Are visual and auditory-visual discriminations predictive of stimulus equivalence? *The Psychological Record, 55,* 197-218.

Waltzman, S. B., & Cohen, N.L. (2000). *Cochlear implants.* New York: Thieme Publishing Group.

Wilkinson, K.M., & McIlvane, W.J. (2001). Methods for studying symbolic behavior and category formation: Contributions of stimulus equivalence research. *Developmental Review, 21,* 355-374.