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Minimal Pairs in the Perception and Production of Speech by Pediatric Cochlear Implant Users: A First Report[1]

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Abstract. The existence of minimal pairs in a language is a traditional type of evidence for the existence of phonemic contrast. This is true both for developed languages and for the languages of acquisitional and clinical populations. This paper examines the relationships among perceptual knowledge of minimal pair contrasts, productive knowledge of minimal pair contrasts, and productive intelligibility of words in sentences in a group of prelingually profoundly deaf children who use cochlear implants. Results showed significant pairwise correlations among the three measures, as well as a number of significant correlations between individual feature classes and overall measures of speech perception, production, and intelligibility.

Introduction

The existence of minimal pairs (see Hyman, 1975) is a traditional type of evidence used to ascertain the phonemic inventory of a language (Bloomfield, 1933), as well as the specific phonological relationship between two given speech sounds. For instance, in the *Grundzüge*, Trubetzkoy (1958/1969) includes the following among the rules for determining phonemic status:

> Rule II.—If two sounds occur in exactly the same position and cannot be interchanged without a change in the meaning of the words or without rendering the words unrecognizable, the two sounds are phonetic realizations of two different phonemes. (p. 48)

A minimal pair can thus be defined as (Trask, 1996):

> Two words of distinct meaning which exhibit different segments at one point but identical segments at all other points. The existence of such a pair demonstrates conclusively that the two segments which are different must belong to different phonemes. (p. 224)

So, for instance, the status of [b] and [d] as representatives of separate phonemes of English can be established by the existence of such minimal pairs as *bill* vs. *dill*, *arbor* vs. *ardor*, and *sob* vs. *sod*. In addition, the existence of a "minimal set" such as *pill* vs. *till* vs. *kill* serves to establish [p^h], [t^h], and [k^h] as representatives of three different phonemes with respect to one another.

The use of minimal pairs as a "discovery procedure" is widespread in descriptive linguistics (especially American Structuralist linguistics[4]) for determining phonemic inventories of developed languages. Additionally, minimal pairs and minimal sets have been used in both clinical and acquisitional studies to determine distributional properties of sound segments and the nature of contrasts. These include studies of dysarthria (e.g., Ansel & Kent, 1992; Kent, Weismer, Kent, & Rosenbek, 1989), hearing impairment (e.g., Boothroyd, 1985; Monsen, 1981), and second language acquisition (e.g., Rogers, 1997).

[4] Note Hockett's (1955) observation that "minimal pairs are the analyst's delight, and he seeks them whenever there is any hope of finding them" [p. 212]

The typical application of minimal pairs to the study of clinical and acquisitional populations involves testing intelligibility. The test format is invariably a single spoken stimulus with a closed response set, constituted by the target word and a number of foils. Listeners hear the stimulus and then choose the word they heard from the response set (orthographic or pictoral representations). The sum of target and foil(s) may produce a minimal pair, a minimal set, or a set of minimal pairs. Kent et al. (1989) suggested that test words should reflect the potential speech production errors observed in the candidate population (dysarthric individuals in Kent et al.); this procedure was followed by, for example, Rogers (1997), who based test words in a forced-choice task on phonetically transcribed errors observed in a group of native speakers of Mandarin speaking English (Rogers, Dalby, & DeVane, 1994). All response sets in Rogers (1997) were minimal pairs, for example, *frog* vs. *fog*, *gone* vs. *gong*, and *cut* vs. *coat*. Response sets in Kent et al. (1989) had four alternatives; each of the three foils forms a minimal pair with the target, for instance, *bad* (target) vs. *bed* (vowel contrast) vs. *bat* (final voicing contrast) vs. *pad* (initial voicing contrast). Finally, the four-alternative response sets in Monsen (1981) included both (overlapping) sets of minimal pairs (e.g., *bit–but–bid–bud*) and true minimal sets (e.g., *look–luck–lack–lock*).

In this paper, we extend the use of minimal pairs testing to a group of pediatric cochlear implant users. We pose two questions. First, what is the relationship between the perception of contrasts and the production of contrasts, as measured by minimal pairs tasks? Second, how are the perception and production of contrasts related to other measures of speech intelligibility? To address these questions, we describe an investigation into the correlations among a minimal pairs perception task, a minimal pairs production task, and a test of words-in-sentences speech intelligibility, both in terms of overall measures and in terms of measures of individual feature classes. For this population, there are specific clinical implications to be derived if control over specific phonological contrasts can be shown to be correlated with more holistic speech intelligibility. Specifically, it helps define the management of reduced speech intelligibility as an eminently tractable problem. Developmental norms for speech and language production have traditionally been established in terms of phoneme-sized units, rather than at higher linguistic levels (e.g., Stoel-Gammon & Dunn, 1985). Comparisons of the phonological development of pediatric cochlear implant users with other populations, especially those with normal hearing, is thus facilitated if similar analytical units form the basis for comparison. Perhaps more important, however, speech production management has traditionally been based on the articulation of individual sounds (Bernthal & Bankson, 1998), so that remediation targets are clearly and narrowly defined. Among these management programs is "Minimal Pairs Treatment" (Gierut, 1989; Weiner, 1981), whose approach to remediation is based on the types of contrasts described in the present paper.

Method

Subjects

Cochlear Implant Users. Users of cochlear implants examined in this study were all of the children followed at the Indiana University School of Medicine who met the following inclusionary criteria: (1) onset of deafness prior to three years of age; (2) implantation before six years of age; (3) use of either the SPEAK or CIS processing strategy from the time of implantation; and (4) available scores for all of the Minimal Pairs (Perception) Test, the Minimal Pairs Production Test, and test of words-in-sentences speech intelligibility. Fourteen children seen regularly at the Indiana University School of Medicine met all of these criteria. All of the children demonstrated profound bilateral hearing losses (mean unaided PTA = 109 dB HL) and received negligible benefit from conventional amplification. Data were obtained at six-month intervals from two years postimplantation until four years postimplantation, and all available intervals for each child were considered during this time period (see Appendix). Twelve of the fourteen children were congenitally deaf, and two of the children experienced early onset of deafness, prior to one year of age (mean age at onset for all children = 0.1 years, *SD* = 0.3 years). Children's age at time of implantation ranged from 2.2 years to 5.3 years (*M* = 3.6 years, *SD* = 1.0 years).

Listeners. Listeners for the Minimal Pairs Production Test were 39 adults between the ages of 18 and 36 who spoke English as a native language, had normal speech and hearing, and had no previous experience listening to the speech of the hearing impaired. Listeners were recruited via a campuswide electronic messaging system that delivers information about campus events and opportunities. This service is available to all faculty, staff, and students of the campus of Indiana University–Purdue University Indianapolis with an electronic mail account. Listeners were paid for their participation in this study.

Materials

Minimal Pairs Perception (MP-Perc). The *Minimal Pairs Test* (Robbins, Renshaw, Miyamoto, Osberger, & Pope, 1988; also described in Kirk, Diefendorf, Pisoni, & Robbins, 1997) was developed as a word recognition test for research investigating the speech perception of children using cochlear implants, hearing aids, and tactile aids (Osberger, Robbins, Miyamoto, Berry, Myres, Kessler, & Pope, 1991). The test consists of 20 minimal pairs of CV(C) words whose initial consonants or vowels differ only in (1) consonant voicing (e.g., *pat–bat*) , (2) consonant place of articulation (e.g., *pea–key*), (3) consonant manner of articulation (e.g., *mom–bomb*), (4) vowel height (e.g., *feet–fat*), or (5) vowel backness (e.g., *beet–boot*). Table 1 shows the 20 pairs of words according to the contrast being tested.

The MP-Perc is administered as a two-alternative forced-choice task with a picture-pointing response mode. On each trial, children are shown a plate with side-by-side pictures of a target word (e.g., *bomb*) and its foil (e.g., *mom*) (the relative positions of target and foil are counterbalanced across trials). An examiner presents a live-voice stimulus consisting of the target word in an auditory-only condition (using a mesh-screen to hide the mouth). The child responds by pointing to the picture of the word that he or she has heard. The MP-Perc consists of four trials of each of the 20 minimal pairs listed in Table 1 (80 trials total), counterbalanced for response order and stimulus. Responses are scored as correct or incorrect, generating an overall percent correct score, as well as percent correct scores for the feature classes consonant voicing, place, and manner; and vowel height and place.

Minimal Pairs Production (MP-Prod). Whenever the MP-Perc was administered, children were also asked to produce each of the words depicted by the pictures used as response plates from either the first half or the second half of the MP-Perc (80 words produced in total). Children were cued to say the word corresponding to each picture by the examiner, using either a pointing or verbal prompt (e.g., "What is this?"). Children's responses were audio-recorded in a quiet therapy room onto high-quality audio-cassettes using a Marantz PMD430 cassette recorder with condenser microphone.

For the present study, one production of each of the 34 different words elicited in this task (some words are members of more than one minimal pair, e.g., *pat–cat* and *pat–fat*) were played for adult listeners with normal hearing ("MP-Prod"). From the audio-cassettes, the 34 words were digitized using CSpeechSP (Milenkovic & Read, 1997), with a 22 kHz sampling rate, 16 bits per sample. Each word was isolated using the CSpeechSP waveform editor and saved to file. Batch files were created for each subject consisting of two repetitions of each of the 34 digitized words, along with stimulus cues ("Number X: ready" "Number X, again: ready") and an ISI of 4 sec (standardized to that used in the words-in-sentences speech intelligibility task, described below). Listener audio-cassette tapes were made from the batch files using the D/A converter on CSpeechSP.

Table 1: Minimal Pairs Test Items by Type of Contrast

Category	Contrast	Minimal Pairs
Voicing	Bilabial voiced vs. Bilabial voiceless	bat–pat bear–pear
	Labiodental voiced vs. Labiodental voiceless	van–fan
	Velar voiced vs. Velar voiceless	goat–coat
Place of Articulation	Bilabial vs. Alveolar	pie–tie
	Bilabial vs. Velar	pea–key cat–pat
	Labiodental vs. Alveopalatal	fell–shell
Manner of Articulation	Oral vs. Nasal	bomb–mom bat–mat
	Stop vs. Fricative	two–shoe pat–fat
Vowel Backness	Front vs. Back	beet–boot bee–boo big–bug pill–pool
Vowel Height	High vs. Low	feet–fat leaf–laugh pea–paw
	High vs. Mid	boot–boat

In the listening portion of the study, each child's half-list productions (34 different words) were monitored by three adults with normal hearing. Stimuli were run through a clinical audiometer (Madsen Electronics OB 822) for sound-field presentation at 70 dB HL to the listeners, who were seated in a sound-attenuated booth. Paper response sheets included, for each trial, the printed target item along with a foil (both in regular orthology), which was the second picture on the plate from which each stimulus item was taken. Listeners were instructed to circle the word that corresponded to the word they heard the child say. The order of target-stimulus on response sheets was counter-balanced across sessions. Each panel heard up to two children but heard the words from each half-list of 34 words no more than once. As with MP-Perc, responses on MP-Prod were scored as correct or incorrect, generating an overall percent correct score, as well as percent correct scores for consonant voicing, place, and manner; and vowel height and place.

Words-in-Sentences Speech Intelligibility (Sentence intelligibility). At each child's testing session, audio-recordings of sentence production were also elicited, as described in Miyamoto, Svirsky et al. (1997). Each child produced 10 sentences that were repeated after an examiner's spoken model. For children under 6 years, one list of the Beginner's Intelligibility Test (BIT) (Osberger, Robbins, Todd, & Riley, 1994) was administered. The BIT utilizes objects and pictures to convey the target sentence, and an imitative response is elicited. Older children (> 6 years old) who could read were administered the Monsen Sentences Test (Monsen, 1983). For this test, children read the sentence silently while the examiner speaks the sentence aloud and then imitates the examiner's spoken model. Each child's sentence productions were audio recorded, digitized, and then played to panels of adult listeners with normal hearing, using the methods described for the MP-Prod. Listeners were instructed to write down everything that they heard the child say. A single panel of three listeners evaluated each set of 10 sentences produced by a single subject. The listeners evaluated more than one set of sentences, but each set was produced by a different child and contained a sentence list not heard previously by the panel. Scores for individual children were calculated as the average number of words correctly understood across the three listeners.

Analyses. Several Pearson product-moment correlational analyses were conducted using SigmaStat (Version 2.0). First, three pairwise correlations were determined for the overall scores for MP-Perc, MP-Prod, and sentence intelligibility. Second, scores from the five feature classes from the MP-Perc were compared with the corresponding scores for the five classes from the MP-Prod. Finally, correlations were determined between scores from the test of sentence intelligibility and the five feature classes from both the MP-Perc and MP-Prod.

Results

Figure 1 shows a scatter plot and regression line for the correlation of overall scores from MP-Perc and MP-Prod. There was a significant correlation ($r = +.56$, $p < .01$) between overall scores on the MP-Perc and overall scores on the MP-Prod.

Insert Figure 1 about here

Results also showed strong, statistically significant correlations between sentence intelligibility and both MP-Perc ($r = +.71$, $p < .001$) and MP-Prod ($r = +.65$, $p < .001$). The correlation between sentence intelligibility and MP-Perc was particularly high, supporting previous findings regarding correlations among different measures (Pisoni, Svirsky, Kirk, & Miyamoto, 1997).

Table 2 shows the correlations between each of the five feature classes (consonant voicing, place, manner; vowel height, backness) from the MP-Perc and MP-Prod. As Table 2 shows, the only significant correlation between an MP-Perc feature and its corresponding MP-Prod feature was for consonant manner ($r = +.41$, $p < .05$). In contrast, correlations observed for the remaining consonant features and both vowel features were generally low, and none were statistically significant.

Table 2: Correlations: MP-Perc and MP-Prod Feature Classes (N = 25)

	MP-Perc				
	Consonant Voicing	Consonant Place	Consonant Manner	Vowel Height	Vowel Backness
MP-Prod	*r*				
Consonant Voicing	+.32	—	—	—	—
Consonant Place	—	+.07	—	—	—
Consonant Manner	—	—	+.41*	—	—
Vowel Height	—	—	—	-.01	—
Vowel Backness	—	—	—	—	+.30

*$p < .05$

Table 3 shows correlations between sentence intelligibility and the five feature classes for both MP-Perc and MP-Prod. As indicated in Table 3, all five MP-Perc feature classes correlated significantly with sentence intelligibility. However, in contrast to the pattern of results observed for the speech perception feature classes, only the voicing feature class from MP-Prod correlated significantly with sentence intelligibility. All other correlations between intelligibility and MP-Prod feature classes were modest, and none of them reached statistical significance.

Table 3: Correlations: Sentence Intelligibility and MP-Perc/MP-Prod Feature Classes (*n* = 25)

	r
MP-Perc	
Consonant Voicing	+.45*
Consonant Place	+.61**
Consonant Manner	+.57**
Vowel Height	+.64***
Vowel Backness	+.64**
MP-Prod	
Consonant Voicing	+.60**
Consonant Place	+.36
Consonant Manner	+.33
Vowel Height	+.21
Vowel Backness	+.20

*$p < .05$, **$p < .01$, ***$p < .001$

Discussion

The results of this investigation indicate a general trend whereby children who receive a cochlear implant implementing either the CIS or SPEAK processing strategy demonstrate intercorrelations among the perception of contrasts, the production of contrasts, and sentence intelligibility. This was demonstrated using the Minimal Pairs Perception Test (MP-Perc), the Minimal Pairs Production Test (MP-Prod), and either BIT or Monsen sentences (sentence intelligibility). Results showed a positive correlation between MP-Perc and MP-Prod, which both test control over contrasts by means of an identical set of minimal pairs. Moreover, sentence intelligibility was also significantly correlated with both MP-Perc and MP-Prod; the latter correlation is similar to Boothroyd's (1985) correlation of sentence intelligibility and "contrast intelligibility." Further, it was demonstrated that individual feature classes may correlate with each other across MP-Perc and MP-Prod, as well as with sentence intelligibility. Data and results from the present investigation are in agreement with previous studies concerning the interrelationships among sentence intelligibility, speech perception, and speech production (Miyamoto, Kirk, Robbins, Todd, & Riley, 1996; Miyamoto, Kirk et al., 1997).

It might be expected that the perception of specific feature classes would correlate with the production of those same classes. That is, the correct perception of a consonant place contrast would correlate with its correct production, the production of vowel height with the perception of vowel height, and so forth. Results from this study, however, indicated a significant correlation only for consonant manner. For all other perception/production feature class pairs, correlations were low and not statistically significant.

This result is on its face surprising, but such surprise stems from the assumption that there would be a one-to-one mapping between perception and production at the *exact* level of linguistic analysis tested in MP-Perc and MP-Prod. There are at least two alternative views of this relationship. First, recall that, for instance, the "consonant place" category of contrast is based on several individual contrasts: bilabial vs. alveolar, bilabial vs. velar, and labiodental vs. alveopalatal. Thus, it is possible that *specific* contrasts may correlate between perception and production, but others may not. Consequently, given the sum of these relationships, *classes* of contrasts between perception and production may not correlate. Second, the correlational analyses performed in this study concentrated on single feature classes, for example, only consonant place in perception with only consonant place in production. This does not account for possible interrelationships between multiple feature classes that might contribute to the overall correlation between perception and production. Thus, for example, although perception place and production place do not correlate, an interrelationship between place and manner may contribute to the correlation between overall speech perception and overall speech production. In addition, it may be difficult to obtain significant correlations with the small number of samples used in this study. If the total number of samples was increased, significant correlations might emerge for other feature classes.

Although both MP-Perc and MP-Prod were highly correlated with sentence intelligibility, one may not have predicted that the correlation between MP-Perc and intelligibility ($r = +.71$, $p < .001$) would be greater than that of MP-Prod and intelligibility ($r = +.65$, $p < .001$). First, the correlation coefficient for overall MP-Perc and intelligibility was higher than for overall MP-Prod and intelligibility. In addition, all five MP-Perc feature classes correlated significantly with intelligibility, but among the MP-Prod feature classes, only voicing did. Apparent discrepancies between expected relations and those borne out by the data can be explained in part by lack of variance in some of the data. Table 4 displays sample means and standard deviations for the five MP-Prod feature classes.

Table 4: Descriptive Statistics: Sentence Intelligibility and MP-Prod Feature Class (*n* = 25)

	***M* Percent Correct**	***SD***
Sentence Intelligibility	47%	28.9%
MP-Prod Consonant Voicing	72%	20.1%
MP-Prod Consonant Place	91%	8.3%
MP-Prod Consonant Manner	80%	18.0%
MP-Prod Vowel Height	96%	6.9%
MP-Prod Vowel Backness	96%	5.5%

As Table 4 indicates, scores for the MP-Prod feature classes consonant place, consonant manner, vowel height, and vowel backness were close to ceiling (*M* percent correct across the four feature classes = 91%), and standard deviations were small (*M* = 6.9%). On the other hand, sentence intelligibility and MP-Prod consonant voicing, which correlated significantly ($r = +.60$, $p < .01$), exhibited much more variance. Thus, a lack of variance may have contributed to the absence of expected significant correlations throughout the data.

Although past research has established a high correlation between phonological characteristics and overall speech intelligibility (e.g., Smith, 1975), it would not be unexpected that specific correlations might be task-dependent. In the present study, both MP-Prod and sentence intelligibility were measured as the percent of words heard correctly by listeners. However, the two tasks differed in important ways. First, sentence intelligibility was scored as correct words *in sentential contexts*, whereas MP-Prod was based on words heard in isolation. Thus, the sentence intelligibility task offered syntactic, semantic, and pragmatic cues that were on the whole absent from MP-Prod. Second, MP-Prod (along with MP-Perc) measures only a limited number of potential contrasts and measures these only in either the onset or the nucleus of single syllable words. Thus, although the conceptual relationship between sentence intelligibility and MP-Prod may be patent, further examination reveals many structural differences between the two that might lead to a correlation that is lower than expected.

Further cautionary notes can be raised regarding the interpretation of the results of this study. First, the traditional concept of a "minimal pair" refers to a procedure for establishing the contrastive nature of segments, rather than of features or values of features. The relevant segments of a minimal pair may thus differ from each other on a scale ranging from a minimal opposition (i.e., in a single feature; see Jakobson, 1949) to a maximal one, and regardless of the source or magnitude of the contrast, the existence of the minimal pair is evidence for the phonemic status of the relevant segments. The three traditional categories for the description of consonants (voicing, place of articulation, manner of articulation; Ladefoged, 1993) may thus give rise to minimal pairs whose relevant segments differ in from one to three features: (1) voicing only: e.g., *bill* vs. *pill*, (2) voicing and place: e.g., *bill* vs. *till* (also voicing and manner, place and manner), and (3) voicing, place, and manner: *bill* vs. *sill*. The MP-Perc (and thus MP-Prod) is constructed of pairs whose relevant segments differ generally by a single phonetic feature, but sometimes by two. As Table 1 shows, both the voicing and place of articulation categories consist of pairs that differ only in voicing or place of articulation. However, the ostensible "stop vs. fricative" pairs in the manner of articulation category differ in place as well as manner. Likewise, one of pairs that test vowel backness (*big–bug*) also exhibits a height difference, and one pair that tests vowel height (*pea–paw*) also shows a difference in backness. The presence of nonminimal oppositions within the MP-Perc and MP-Prod most likely has no profound effect on the interpretation of overall scores, but may well confound the interpretation of individual feature class scores. It is relatively clear, for example, that an incorrect response on *pat–fat* indicates a lack of contrast between [p] and [f], but it is not clear whether this is attributable to a lack of manner contrast or a lack of place contrast (the MP-Perc instructions [Robbins et al., 1988] sanction scoring this only under manner of articulation). Thus, some refinement in the instruments (both MP-Perc and its derived MP-Prod) would be necessary for fine analyses based on feature oppositions.

Second, any interpretation of results from the tasks described here as regards the ability to "perceive a contrast" or to "produce a contrast" should be viewed with caution. Both the MP-Perc and MP-Prod are single-stimulus, two-alternative forced-choice tasks, so that the actual contrasts as revealed in the minimal pairs inhere, not in the stimuli, but rather in the responses. Further, the two-alternative forced-choice task has little to do concerning the "correctness" of a production. The task is not merely a matter of hearing one of the possible responses, but also of *not* hearing the other one.[5] Modifications in the administration protocol might better capture children's abilities to perceive or produce the contrasts. For example, MP-Perc could be administered as a same-different task, so that children would hear two tokens and decide whether these were instances of the "same" speech sound or of "different" speech sounds. MP-Prod could be administered in much the same way, using children's productions as stimuli and listeners' decisions as responses. Again, results would require careful interpretation, since there always exists the possibility that children's phonological systems may contain the same number of contrasts as adult systems but not the same implementation strategies; that is, the *existence* of a contrast

[5] In this regard, note Saussure's (1916/1985) assertion that phonemes are *negative entities*: "Or ce qui les caractérise, ce n'est pas, comme on pourrait le croire, leur qualité propre et positive, mais simplement le fait qu'ils ne se confondent pas entre eux. Les phonèmes sont avant tout des *entités oppósitives, relatives et négatives*" (p. 164; emphasis added).

might be inferred, but not necessarily the *nature* of a contrast. Other possibilities for alternative task conditions include an ABX format and open-set responses to single stimuli, although the latter still lacks explicit presentation of the relevant contrasts.

Finally, the present study has considered data from all available testing intervals for those children who met the inclusionary criteria (see Appendix). We concede that the use of multiple data points from identical subjects may bias the results, specifically the correlation coefficients. Future studies will reconsider this methodology in the light of additional data that may become available from individual children.

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Appendix

Available Subject Data

Subject	Years Postimplantation				
	2.0	2.5	3.0	3.5	4.0
GD	X				
KN			X		X
GL	X	X	X		
LE		X			
MO	X	X			
KT			X		X
IY					X
WB	X		X		
KR	X		X		
IN	X	X			
MB			X		
WE			X		
IV	X	X	X		
IW		X	X		

Note: Subjects are listed by arbitrary two-letter designation that do not correspond to initials. An "X" in a cell indicates that MP-Perc, MP-Prod, and sentence intelligibility scores were available for that child and that interval.

Figure caption

Figure 1: Scatterplot and regression line for percent correct MP-Perc (x-axis) and MP-Prod (y-axis). Each data point represents a single child at a single testing interval.