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Development of Lexical Connectivity in Pediatric Cochlear Implant Users¹

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Abstract. The present study examined the performance of pediatric cochlear implant (CI) users on easy (high frequency words from low density neighborhoods) and hard (low frequency words from high density neighborhoods) words on the monosyllabic Lexical Neighborhood Test (LNT) and Multi-syllabic Lexical Neighborhood Test (MLNT). The easy—hard effect (the superior performance on easy words compared to hard words) increased slightly on the LNT for Oral Communication (OC) users but not for Total Communication (TC) users as lexicon size increased. The easy—hard effect was invariant as a function of lexicon size for both OC and TC users on the MLNT. Similarly, the word length effect (the superior performance for long words on the MLNT compared to short words on the LNT) did not vary as a function of lexicon size for either OC or TC users. The size of the easy—hard effect was not correlated with the size of the word length effect for either class of users. When lexicon size was controlled for, OC users performed better on both the LNT and MLNT than did TC users. These results were discussed in terms of how the mental lexicon of CI users develops over time and the role of lexical connectivity in spoken word recognition.

Introduction

Because traditional word recognition tests underestimate the ability of hearing impaired children to comprehend spoken words, Kirk, Pisoni, and Osberger (1995) developed two new spoken word recognition tests, the Lexical Neighborhood Test (LNT) and the Multisyllabic Lexical Neighborhood Test (MLNT). Both tests involve open-set identification of words spoken in isolation (but see Eisenberg, Martinez, Holowecky, & Pogorelsky, 2002 for an extension of these tests to recognizing words in sentences). The LNT uses only monosyllabic words; the MLNT uses two and three syllable words.

Two major criteria were used when selecting items from the test. First, each word used in the test should have a relatively high probability of being in the child's lexicon. Kirk et al. (1995) noted, for example, that fewer than 1/3 of the words on the commonly used Phonetically Balanced Kindergarten (PB-K) test are found in Logan's (1992) computational analyses of the CHILDES database (MacWhinney & Snow, 1985). A child could, in theory, accurately reproduce an unknown word, if all the word's phonetic details are accurately perceived. If, however, the child perceives only some information for a portion of the word, then he/she needs to make an educated guess concerning what the word is. That educated guess is likely to be confined to words in the child's lexicon and not to include words unfamiliar to the child. The result would be lower scores on a test containing a higher proportion of words unknown to the child. To avoid this bias, in their new tests, Kirk et al. used only words produced by children from 3 to 5 years of age (Logan, 1992).

Second, Kirk et al. (1995) selected their test words in accordance with the assumptions of prevailing theories of spoken word recognition (Auer & Luce, 2005; Luce & Pisoni, 1998, Marslen-Wilson 1987, 1989; McClelland & Elman, 1986; Norris, 1994). In particular, they included in each of their test sets, two types of words—some predicted by these theories to be easy and some predicted to be hard. Words with a high frequency of occurrence in the language (e.g., Kucera & Francis, 1967) are typically easier to recognize than words with a lower frequency of language (e.g., Andrews, 1989; Elliot, Clifton, & Servi, 1983; Howes, 1957; Pollack, Rubenstein, & Decker, 1959; Savin, 1963). In addition, words phonetically similar to few other words are generally easier to recognize than words phonetically similar to many other words (e.g., Luce & Pisoni, 1998; McClelland & Elman, 1986; Treisman, 1978a,

1978b; Vitevitch & Luce, 1999). The single phoneme Deletion, Addition, and Substitution (DAS) rule is frequently used to operationally define phonetic similarity (Eukel, 1980; Greenberg & Jenkins, 1964; Landauer & Streeter, 1973). Two words are considered phonetic neighbors (and hence phonetically similar to one another) if one can be changed into the other by the deletion, addition, or substitution of a single phoneme. Words with many neighbors are said to come from high density neighborhoods; those with fewer neighbors to come from low density neighborhoods. The finding that words from low density neighborhoods are easier to recognize than words from high density neighborhoods is referred to as the neighborhood density effect.

The word frequency effect and the neighborhood density effect are both compatible with the general predictions of several current models of spoken word recognition (e.g., Luce & Pisoni, 1998; Marslen-Wilson 1987, 1989; McClelland & Elman, 1996; Norris, 1994, Treisman, 1978a). Indeed, they are two fundamental facts which such models must account for. The Neighborhood Activation Model (NAM) of Luce and Pisoni (1998), for example, assumes that a spoken word activates its representation in the mental lexicon and also the representations of its phonetic neighbors. A probabilistic decision rule is then used to select among the activated representations. The activation levels themselves are adjusted multiplicatively by the word's frequency of occurrence, biasing the recognition process towards more common words.

In developing their LNT, Kirk et al. (1995) selected half of their words to be "easy" and half to be "hard." Easy words were a) above the median frequency of usage in Logan's (1992) corpus of the speech of 3 to 5 year olds, and b) below the median neighborhood density in Logan's corpus. Hard words, in contrast, were below the median frequency of usage and above the median neighborhood density. Words in the LNT were restricted to monosyllabic words. Similarly, in the MLNT, easy words were words above the median frequency of usage for multisyllabic words and below the mean neighborhood density for multisyllabic words. Hard words were below the median frequency and above the median neighborhood density for multisyllabic words. Words in the MLNT were restricted to multisyllabic words.

Note that because monosyllabic words tend to be used more frequently and come from higher density lexical neighborhoods (Gruenenfelder & Pisoni, 2005) than multisyllabic words, the cutoff values used in the LNT differed from those used in the MLNT. In particular, for monosyllabic words, the median frequency in the Logan (1992) corpus was four occurrences and the median density was four neighbors. These were the cutoff values used in constructing the LNT. In contrast, for multisyllabic words, the median frequency was two occurrences and the median density was zero neighbors, and these were the cutoffs used in constructing the MLNT.

Not surprisingly, at least in open-set tests, when lists constructed in this manner are used, easy words are recognized more easily by normal hearing adults than hard words (e.g., Sommers, Kirk, & Pisoni, 1997). Sommers et al. found the same result for CI users who were apparently deafened as adults and were implanted as adults. Kirk, Pisoni, and Miyamoto (1997) found similar results with mildly to moderately impaired adult listeners. Similarly, normal hearing children listening to amplitude-reduced speech, normal hearing children listening to spectrally degraded stimuli, and hearing impaired children using CIs are better able to recognize easy words than hard words, both when the words are spoken in isolation and when they are part of a meaningful (though not overly semantically constrained) sentence (Eisenberg, Martinez, Holowecky, & Pogorelsky, 2002). Bell and Wilson (2001) reported similar results for normal hearing adults listening to sentences in noise. These findings replicate the word frequency and neighborhood density effects mentioned above.

More significantly, Kirk et al. (1995) found a similar easy-hard effect in hearing impaired children using cochlear implants. Pediatric cochlear implant (CI) users more accurately identified easy words than hard words in both the LNT and the MLNT. In addition, a word length effect was also found: pediatric CI users performed better on the MLNT (multisyllabic words) than on the LNT (monosyllabic words). Similar results were found by Kirk, Eisenberg, Martinez, and Hay-McCutcheon (1999). Kirk et al. (1995) interpreted the easy-hard effect to mean that CI users, like normal hearing adults, organize their mental lexicon into similarity neighborhoods of words and that they use this organization when identifying spoken words.

The present paper uses the LNT and MLNT developed by Kirk et al. (1995) to address three different issues. The first concerns the “representational specificity” of the phonetic categories used by pediatric CI users when recognizing spoken words. To the extent that CI listeners use relatively broad phonetic categories, we might expect relatively robust easy-hard effects. In a test involving the recognition of isolated words, broad phonetic categories force the CI user to make educated guesses concerning the identity of each test word based on what amounts to limited phonetic input. Given an easy word—a high frequency word with few neighbors—that guess is relatively likely to hone in on the correct word. In the case of an easy word, there are, in effect, fewer phonetically similar distractors competing for recognition. If the guess is primarily confined to the actual word’s neighbors, then the fewer the neighbors, the more likely is the guess to be correct, resulting in an easy-hard effect. Further, to the extent that the CI user is biased towards guessing higher frequency words (cf. Luce & Pisoni, 1998), easy words are more likely to be guessed correctly than hard words, resulting in an even larger easy-hard effect.

Over time, as phonetic representations become more refined and detailed, such educated guessing is less necessary, and the easy-hard effect should thus become smaller. In fact, if the phonetic categories were fine enough to discriminate all the words in the CI user’s mental lexicon, then performance for both easy and hard words would be at ceiling and no easy-hard effect would occur. Exactly such a phenomenon is evident with normal hearing listeners. These listeners perform near ceiling on isolated words heard in the clear, i.e., at high Signal-to-Noise ratios. Only when the words are spoken in noise or are distorted in some way does the easy-hard effect emerge (e.g., Sommers et al., 1997). This reasoning suggests that the easy-hard effect should be relatively large shortly after the listener has received a CI (but long enough after so that the CI user is adequately perceiving some phonetic information) and then gradually diminish as the CI user gains experience with the device. Accordingly, the first purpose of the present paper was to examine the development of the easy-hard effect as a function of the time after implant.

Consistent with this reasoning, Eisenberg et al. (2002) found a somewhat larger easy-hard difference in a group of low performing CI users ($N = 3$) than in a group of high performing CI users ($N = 9$). However, the sample sizes were small. Consequently, no statistical analyses comparing the two groups were performed and the difference between groups is unlikely to have reached statistical significance if such analyses had been performed. Eisenberg et al. did find a larger easy-hard effect for normal-hearing children listening to spectrally degraded speech (The speech was reduced to four spectral channels.) than for normal-hearing children listening to speech in the clear albeit at reduced intensity (25 and 30 dBA). Overall, percent correct for children listening to intensity-reduced speech was higher (~65% correct) than for children listening to spectrally-degraded speech (~55% correct), suggesting that the latter group was extracting broader phonetic categories from the stimuli than was the former group. This finding is consistent with the hypothesis above that easy-hard effects should become smaller as phonetic information becomes more refined. On the other hand, the high performing CI users in Eisenberg et al.’s study showed an easy-hard effect of the same magnitude as the children listening to

intensity-reduced speech, even though their overall performance level was considerably higher (~85% correct).

An alternative view suggests a quite different time course of the development of the easy-hard effect. At early test intervals after receiving an implant, CI users' mental lexicon of **spoken** words may be quite small. When the mental lexicon is small, performance on these tests is likely to be relatively poor, simply because the child does not know many of the words on the tests. Further, because the lexicon is small, statistically any given word is unlikely to have many neighbors and hence no neighborhood density effects emerge. As the lexicon grows, words acquire neighbors and neighborhood density effects begin to emerge. The result should be that, to the extent that the easy-hard effect is at least partially due to neighborhood density (and not entirely to word frequency), the easy-hard effect should grow over time, until easy words begin to reach ceiling and the hard words catch up. Another way of stating this prediction is that over time, performance on easy words should improve faster (until it reaches ceiling) than performance on hard words, and, to the extent that the LNT/MLNT difference also reflects neighborhood density, performance on the MLNT should improve faster than performance on the LNT.

A second issue addressed in this paper concerns the origin of the word length effect. There are at least two possible reasons why multisyllabic words are recognized more easily than monosyllabic words by CI users (as well as by normal hearing adults). First, CI users may be sensitive to word length, in terms of number of syllables, as a word recognition cue. More specifically, it may be easier for them to extract word length information from a spoken word than it is to extract fine phonetic information. Given partial phonemic information, word length may help CI users choose one lexical representation from among several competing representations. That is, if the listener knows the word contains two syllables, then any competing representations of monosyllabic or trisyllabic words can be eliminated.

The second possible reason for the word length effect concerns differences in neighborhood density of the words used in the MLNT and LNT. In Logan's (1992) corpus, multisyllabic words tended to have fewer neighbors (and to occur with lower frequency) than monosyllabic words. (Similarly, if a lexicon more representative of that of college students is used, for example, Nusbaum, Pisoni, & Davis, 1984, multisyllabic words have fewer neighbors and a lower frequency of occurrence than do monosyllabic words.) For monosyllabic words, the median number of neighbors in Logan's corpus was 4 (range 0 – 19). The median frequency of occurrence was also 4 (range 1 – 519). In contrast, for multisyllabic words, the median number of neighbors was 0 (range 0 – 7). The median frequency of occurrence was 2 (range 1 to 100). To the extent that the effects of neighborhood density are stronger than those of word frequency, the word length effect may occur not because CI users are sensitive to word length but because MLNT words come from less dense neighborhoods than do LNT words and are therefore less confusable with other phonetically similar words.

To summarize, the word length effect may be due to CI users' sensitivity to the syllabic structure of words or it may be due to neighborhood density differences between shorter and longer words. We made a preliminary attempt to disentangle these two hypotheses by comparing the time course of development of the easy-hard effect with that of the word length effect. To the extent that these time courses parallel one another, the hypothesis that both effects are due to the same underlying variable is supported. To the extent that the two effects develop with different time courses, the hypothesis that they have different causes—viz. neighborhood density for the easy-hard effect and number of syllables for the word length effect—would be supported.

We realize that this test is less than ideal, especially given that MLNT words have lower frequency of occurrences than LNT words, which should work against a word length effect. Nevertheless, we think that this approach could provide at least a starting point in better understanding of the word length effect.

The third issue we explored in the current paper concerned the effects of early experience on spoken word recognition in deaf children with CIs. More specifically, we examined differences in the structure of the mental lexicon of oral communication (OC) CI users and total communication (TC) CI users. Although Kirk et al. (1995) used both types of users in their original report, they did not report results separately for the two groups. We might expect that TC users extract broader phonetic categories from the acoustic stimulus than do OC users, simply because TC users rely more on non-phonetic cues for understanding language than do OC users. If so, then TC users should show larger easy-hard effects than do OC users. Alternatively, it may be that TC users organize their mental lexicons in an entirely different manner than normal hearing adults and OC CI users. What is phonetically similar to TC users may not be phonetically similar to OC users, and vice versa. In that case, we might expect to see a greatly reduced easy-hard effect in TC users.

Method

Participants

The participants were 138 children receiving services at the Indiana University Medical Center who had provided informed consent allowing the use of their test results for research purposes. Different analyses included different subsets of these 138 participants. Hence, this group is referred to as the master group. All participants had CIs and all test results reported here were collected after the implant had been received. Testing was done as part of the participant's regular post-implant clinical appointments. Most children were tested during multiple appointments, each appointment being approximately an integer multiple of 6 months post-implant. A test interval of 0 corresponds to as near as possible immediately after implant, a test interval of 1 to 6 months post-implant, a test interval of 2 to 12 months post-implant and so on. Table 1 shows some characteristics of the participants. Ninety of the participants were users of Oral Communication (OC) and 48 were users of Total Communication (TC).

	Mean (mos.)	SD (mos.)
Age at Onset	6.45	19.22
Age at Implant	47.20	26.50
Age at First Test Interval	92.47	32.11

Table 1. Characteristics of the master group of 138 participants.

Procedure

Each child received a battery of tests at each interval. The tests a particular child received at a given interval were not necessarily the same as those received by another child at the same interval, nor were they necessarily the same as those that child had received at the previous interval. We created a master file by selecting all intervals for each child in which the child had received the LNT test. At no interval did a child receive the MLNT without also receiving the LNT. Hence, this procedure includes all the LNT and MLNT data collected from these children. Since most children received the LNT at multiple

test intervals, most contributed multiple data points in this master file. The master file included data from 443 test intervals across the 138 children. Hence, the mean number of intervals on which each child was tested was 3.22 (S.D.=1.91). The mean interval after implant at which testing occurred was 9 (S.D.=4.47).

Appropriate subsets of data were then selected from this master file according to the specific hypotheses being tested. For example, when testing a hypothesis involving only LNT scores, data from all 443 test intervals were included. In contrast, when testing a hypothesis concerning the relation of LNT and MLNT scores, only those test intervals were included where a child had contributed both LNT and MLNT scores. The specific subsets of data included in each analysis are described in the results section. The general procedures for administering the LNT and MLNT at the Indiana University Medical Center are described in Kirk et al. (1995).

Results

Changes in the Easy-Hard Effect with Lexicon Size

The first issue that we investigated concerned changes in the easy—hard effect as a function of the size of the child’s lexicon. Overall performance on the LNT was used as a measure of lexicon size. Figure 1 is a scatter plot of the easy-hard effect as a function of overall LNT percent correct. When all samples from our master group were included, the size of the easy-hard effect correlated positively with LNT performance, $r = 0.28$, $t(441) = 6.13$, $p < .001$, indicating that as the child’s lexicon grew so did the easy-hard effect. This analysis, however, is susceptible to ceiling and especially floor effects. A child with no lexical knowledge at all would score 0% on the LNT, showing an easy-hard effect of 0. In contrast, a child with some lexical knowledge would show a positive easy-hard effect. Mixing scores from two such populations would result in an overall positive correlation between the easy-hard effect and LNT performance.

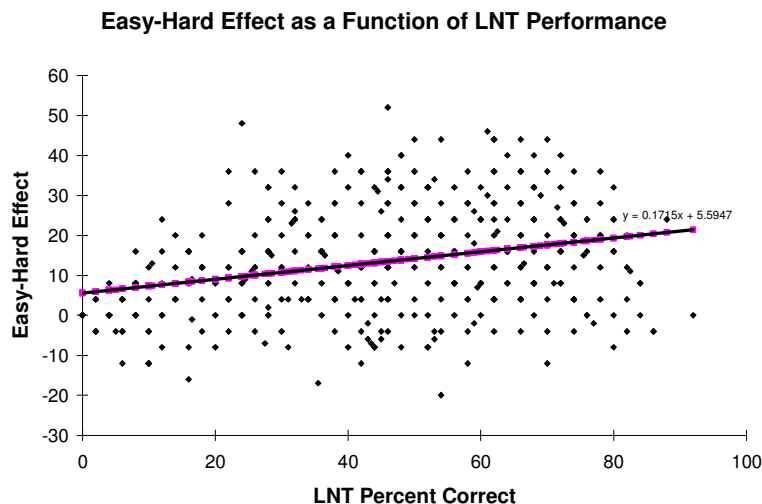


Figure 1. Size of the easy-hard effect as a function of percent correct on the LNT.

To control for floor and ceiling effects, we repeated the correlational analysis after first eliminating all tests in which the child scored 20% or less on the LNT (a total of 73 tests) and all tests in which the child scored above 80% correct on the LNT (a total of 12 tests). These corrections reduced the

correlation to 0.11. Although statistically significant, $t(356) = 2.09$, $p < .05$, the correlation is quite small and explains less than 1.25% of the total variance. Essentially, this result suggests that the size of the easy-hard effect is not correlated with overall LNT performance.

To help ensure that we were not missing a more subtle relation between the easy—hard effect and overall LNT performance, we selected from our master group all test intervals in which overall LNT performance was 21-40% correct ($N=96$), all those in which overall performance was 41-60% correct ($N=142$), and all those in which overall performance was 61–80% correct ($N=120$). Figure 2 plots performance on LNT easy words and LNT hard words for these three performance intervals. The easy-hard effect for these three performance intervals was 13.38, 15.42, and 17.93, respectively. An analysis of variance showed that the increase in the effect with performance interval was reliable, $F(2, 355) = 3.19$, $p < .05$. Individual t tests showed that the easy-hard effect was smaller in the 21-40% correct group than in the 61-80% correct group, $t(214) = 2.62$, $p < .01$. All other pair-wise comparisons were non-significant.

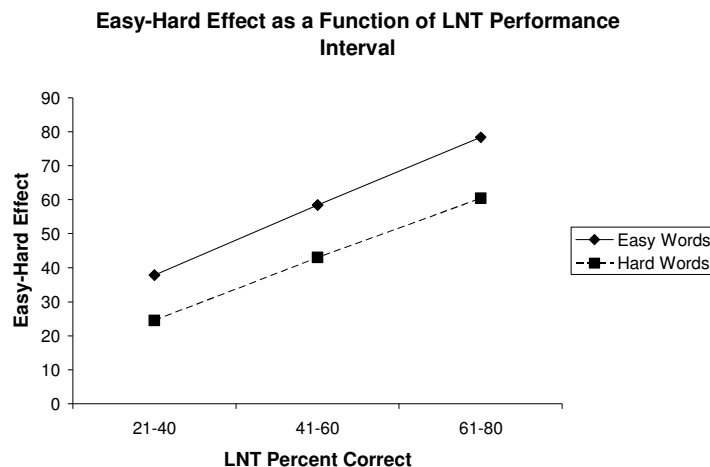


Figure 2. The easy—hard effect as a function of LNT performance interval.

The easy-hard effect is not, of course, arithmetically independent of the LNT Percent Correct, since the overall percent correct is simply the mean of the percent correct on easy words and the percent correct on hard words. Therefore, we also examined the relation between the easy-hard effect and performance on a different measure of lexicon size, PPVT raw scores. We first selected from our master group of 453 test intervals, the 358 on which the child had scored between 21 and 80% correct, inclusive, on the LNT. From this group, we then selected for additional analyses the 350 test intervals for which PPVT scores were also available. The overall correlation between LNT percent correct and PPVT raw scores was 0.177. Although statistically significant, $t(348)=3.35$, $p < .001$, the magnitude of the correlation is surprisingly low given that both tests purport to measure the size of a child’s vocabulary.

Figure 3 shows a scatter plot of the easy—hard effect as a function of PPVT performance. The correlation between PPVT raw score and the size of the easy—hard effect was 0.116, $t(348) = 2.18$, $p < .05$. To further examine this effect, test records were divided into four sub-groups based on overall PPVT performance. The bottom 25 percent of records, based on PPVT performance, were assigned to Quartile 1, records in the next poorest performing 25% were assigned to Quartile 2, and so on, with the restriction that when the same PPVT score occurred in multiple test records, those records could not be

split across quartiles. The number of records in Quartiles 1-4 was 88, 90, 85, and 87, respectively. The mean PPVT raw score for Quartiles 1-4, respectively, was 40.35, 63.34, 83.99, and 125.39. Figure 4 shows percent correct on LNT easy words and LNT hard words as a function of PPVT quartile. The easy-hard effect for the four quartiles was 13.68, 14.00, 15.98, and 18.67, a significant increase across quartile, $F(3,346) = 2.66$, $p < .05$. Individual t-tests revealed that the easy-hard effect was significantly smaller in both Quartiles 1 and 2 than in Quartile 4, $t(173) = 2.65$, $p < .01$, and $t(175) = 2.40$, $p < .02$, respectively. The overall results of the PPVT analysis agree with the results of the overall LNT performance analysis. There is a small but statistically significant increase in the easy-hard effect as vocabulary size increases.

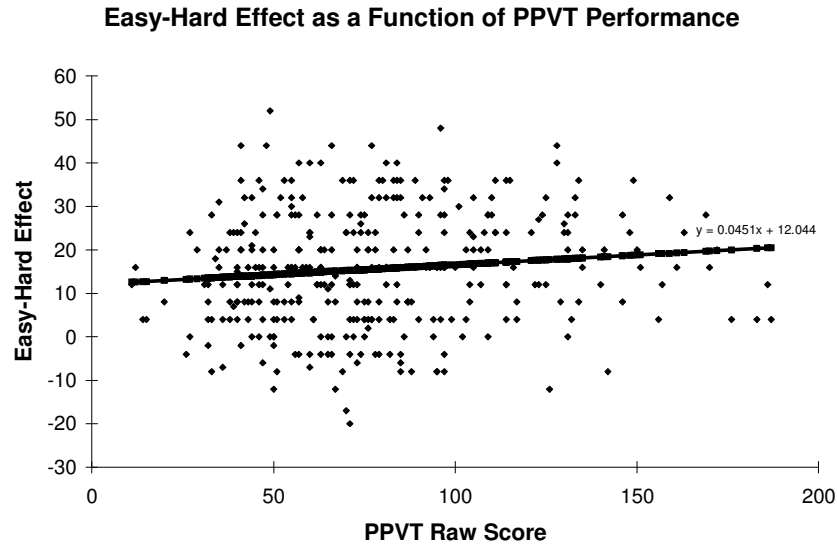


Figure 3. Scatter plot of the LNT easy—hard effect as a function PPVT raw score.

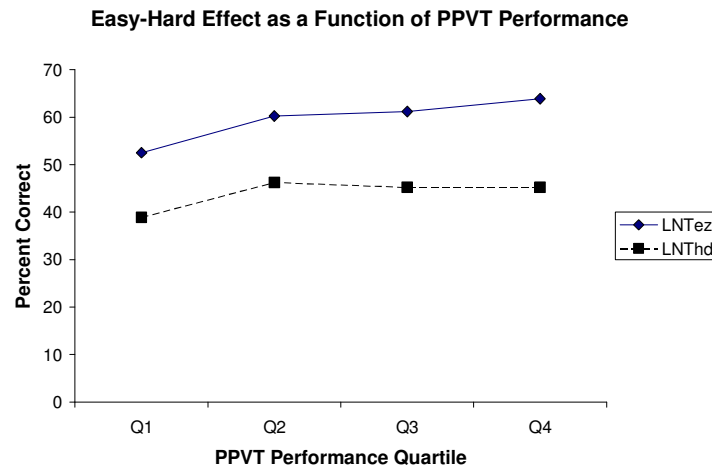


Figure 4. Percent correct on LNT easy and LNT hard words as a function of PPVT raw score performance quartile.

We also examined the easy-hard effect on the MLNT. Our master file of 443 test intervals included 213 on which the child was tested on the MLNT. Eighty-one individual children contributed these data. Figure 5 shows a scatter plot of the easy-hard effect on the MLNT as a function of overall performance on the LNT. Analyzing only those test intervals on which the child scored between 21% and 80% correct (N=162), inclusive, on the MLNT, we found no significant correlation between the MLNT easy-hard effect and overall performance on the LNT, $r = -0.052$, $t(160) = -0.66$.²

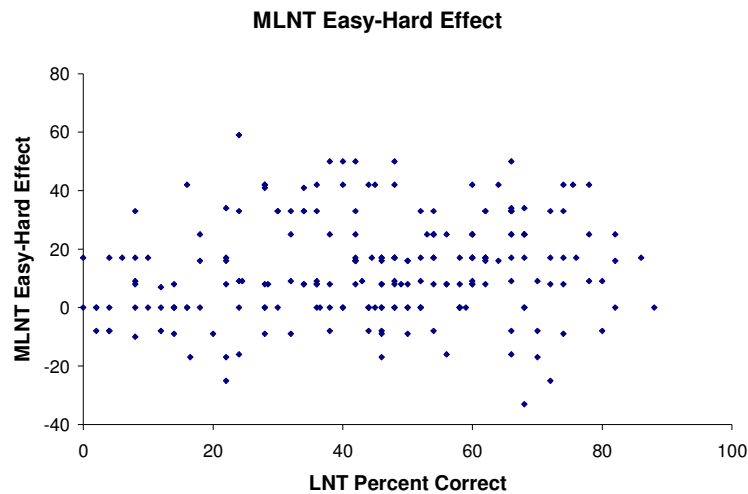


Figure 5. Scatter plot of the easy-hard effect as a function of overall percent correct on the LNT.

Figure 6 shows MLNT performance separately for easy words and hard words, broken down into four quartiles based on LNT performance percentile, with the restriction that test records with identical LNT scores could not be assigned to overlapping quartiles. An analysis of variance found no significant change in the easy-hard effect across these four performance intervals, $F(3, 158) = 1.34$. The MLNT easy-hard effect across the four quartiles, from lowest LNT performance to highest, was 15.32 (N=40), 14.08 (N=39), 11.45 (N=40), and 19.05 (N=43).

We also analyzed the MLNT easy-hard effect contingent on PPVT performance in a manner similar to the analyses done for the LNT data. There were 158 test intervals for which both MLNT and LNT data were available. As was the case for the LNT data, the correlation between PPVT raw scores and MLNT percent correct was small but statistically significant, $r = 0.189$, $t(156) = 2.40$, $p < .02$. The MLNT easy-hard effect did not significantly correlate with PPVT performance, $r = 0.103$, $t(156) = 1.29$. An analysis of variance of the easy—hard effect by PPVT quartile (N = 37, 41, 39, and 41 for Quartiles 1-4, respectively; mean PPVT raw score = 39.87, 63.46, 85.21, and 126.15 for Quartiles 1-4, respectively) also showed no significant effect of PPVT performance on the easy—hard effect, $F(3,154) < 1$. Across the four quartiles, the easy-hard effect was 11.86, 15.46, 15.41, and 17.61.

² Note that we are trimming the data to the 21% to 80% correct range using MLNT scores (in order to avoid floor and ceiling effects in the MLNT easy-hard effect, but we are using LNT scores as the basis for estimating the size of the child's lexicon. In our overall sample of MLNT tests (N = 214), performance on the LNT correlated extremely highly with performance on the MLNT, $r = 0.894$.

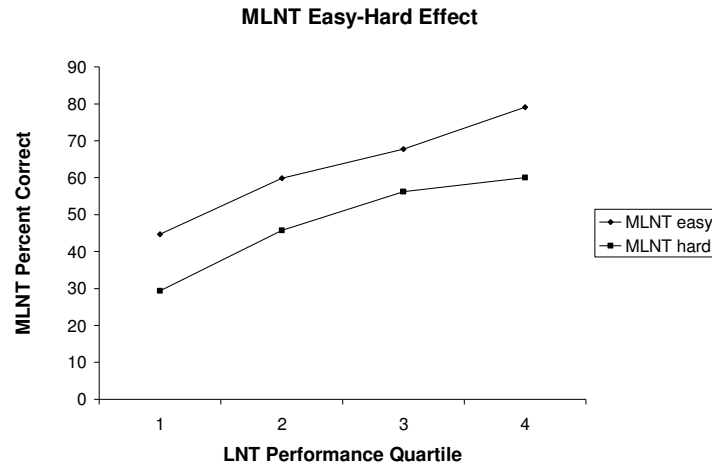


Figure 6. Percent correct on the MLNT easy words and MLNT hard words as a function of MLNT percent correct.

All of the above analyses included both children who used OC and children who used TC. It is quite possible that communication mode can affect the structure of the developing lexicon. In such a case, the easy-hard effect may be quite different in OC users than in TC users. Accordingly, we repeated the above analyses separately for each of these two communication modes. For TC users ($N=113$) performing in the overall range of 21 to 80% correct on the LNT, there was no significant correlation between the easy-hard effect and overall LNT performance, $r = 0.07$, $t(111) = 0.76$. For OC users ($N = 245$) performing in the same range, there was a small but statistically significant correlation, $r = 0.14$, $t(243) = 2.22$, $p < .05$. Note that the difference between these two correlations was itself non-significant.

Figure 7 shows LNT performance separately for easy words and hard words for OC and TC users, broken down into three bins of overall LNT performance: 21-40% correct ($N = 43$ for the OC group; $N = 53$ for the TC group), 41-60% correct ($N = 104$ for the OC group; $N = 38$ for the TC group), and 61-80% correct ($N = 98$ for the OC group; $N = 22$ for the TC group).

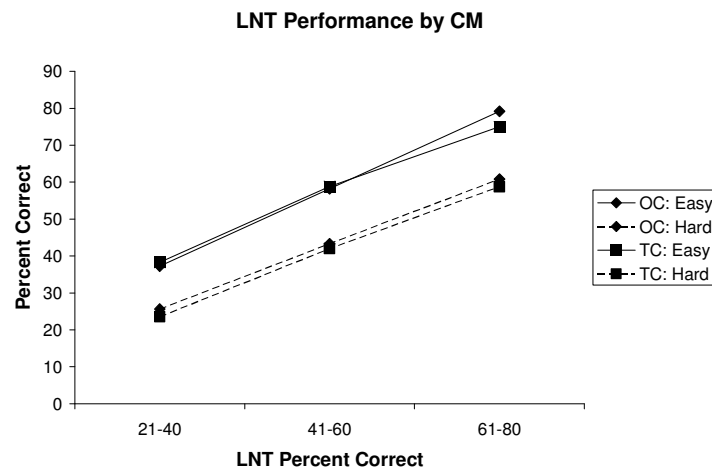


Figure 7: Percent correct as a function of LNT performance bin for easy and hard words for OC users and TC users.

Figure 8 explicitly shows the easy hard effect for the two CM groups. Overall, for the TC group, the easy-hard effect did not change size as a function of performance interval, $F(2, 110) < 1$. However, for the OC group, the easy-hard effect increased as LNT performance improved, $F(2, 242) = 3.98, p < .02$. Individual t -tests comparing performance bins in the OC group indicated that the easy-hard effect was marginally smaller in the 41-60% performance bin than in the 61-80% performance bin, $t(200) = 1.77, p < .10$, and significantly smaller in the 21-40% performance bin than in the 61-80% performance bin, $t(139) = 2.87, p < .005$. Comparisons of the OC and TC group at each individual performance bin were all non-significant, smallest $p = .21$.

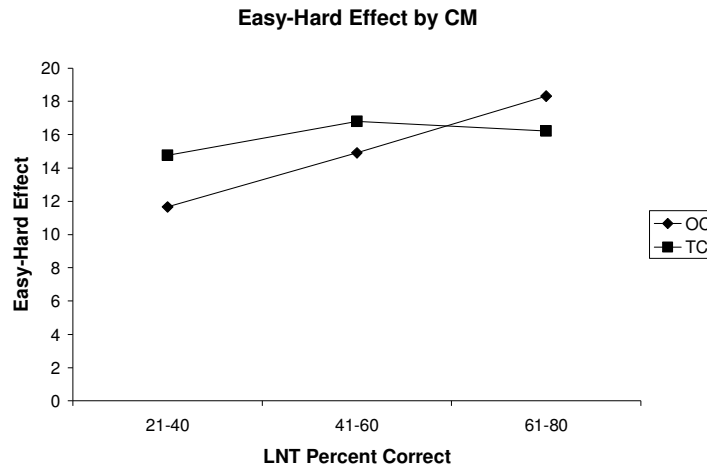


Figure 8. The easy-hard effect as a function of LNT performance bin for OC and TC users.

We also examined the relation between PPVT and LNT performance separately for OC children and TC children. For TC users, PPVT performance did not correlate with LNT performance, $r = 0.110, t(110) = 1.16$, or with the LNT easy-hard effect, $r = 0.056, t(110) = 0.59$. In contrast, for OC users, PPVT performance did significantly correlate with LNT performance, $r = 0.306, t(236) = 4.94, p < .001$, and with the LNT easy-hard effect, $r = 0.141, t(236) = 2.19, p < .05$. Both the OC group and the TC group were broken down into PPVT raw score performance quartiles. Table 2 shows PPVT performance for each of these quartiles for each CM group. Figure 9 shows the percent correct for LNT easy and LNT hard words as a function of PPVT performance quartile separately for the OC and TC groups.

	Q1	Q2	Q3	Q4
OC Users				
N	60	59	60	59
Mean	37.53	58.54	79.20	114.20
Standard Deviation	9.13	6.32	6.03	41.07
TC Users				
N	28	27	28	28
Mean	49.61	71.39	91.16	131.86
Standard Deviation	8.25	5.71	7.50	24.74

Table 2. N, Mean, and Standard Deviations for each of the four PPVT raw score quartiles for OC and TC users used in the LNT analysis.

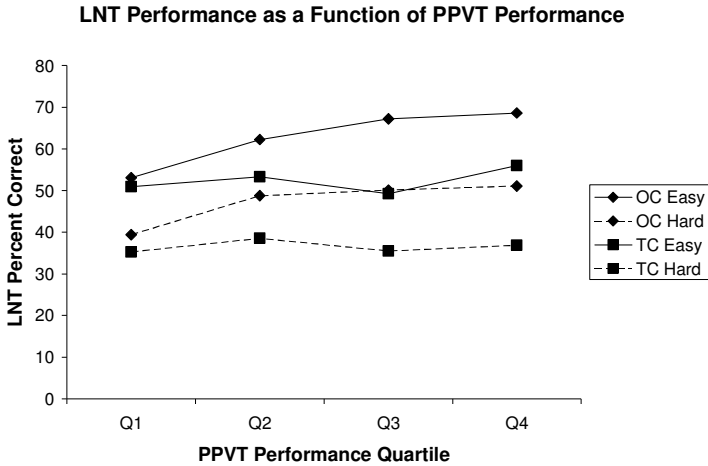


Figure 9. Percent correct on LNT easy and LNT hard words as a function of PPVT Performance Quartile for the OC users and the TC users.

Figure 10 shows the easy-hard effect separately for the OC and TC groups as a function of PPVT performance quartile. The easy-hard effect did not change significantly as a function of PPVT performance quartile for either the TC group, $F(3, 108) < 1$, or the OC group, $F(3, 234) = 1.53$ (despite the small positive correlation between PPVT performance and the easy-hard effect in the OC group).

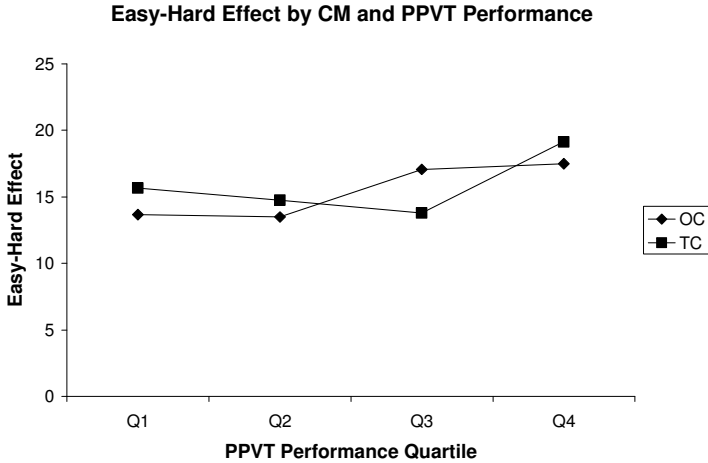


Figure 10. The Easy—Hard effect for OC and TC users as a function of PPVT Performance Quartile.

We also analyzed the easy-hard effect in the MLNT data separately for OC and TC users. MLNT data were available from 97 test intervals involving OC users whose overall MLNT percent correct was in the 21-80% range, and from 65 test intervals involving TC users whose overall MLNT percent correct was in the 21-80% range. For OC users, the correlation between the easy-hard effect for MLNT words and overall MLNT percent correct was $-.08$; the corresponding correlation for TC users was $.01$. Neither correlation was significant. Similarly, the easy-hard effect did not significantly change as a function of

performance bin (21-40%, 41-60%, 61-80%) for either the OC or TC group. For the OC group, the easy-hard effect across the three performance intervals was 16.44, 18.42, and 12.54, $F(2,94) = 1.19$. For the TC group, the easy-hard effect across the three performance intervals was 13.92, 18.89, and 12.61, $F(2,62) < 1$.

The MLNT data were also analyzed using PPVT performance as a measure of lexicon size. For OC users ($N=93$), PPVT performance correlated significantly with percent correct on the MLNT, $r = 0.321$, $t(91) = 3.23$, $p < .01$, but only marginally with the size of the easy-hard effect, $r = 0.178$, $t(91) = 1.78$, $.05 < p < .10$. For TC users ($N=65$), PPVT performance did not correlate significantly with either percent correct on the MLNT, $r = 0.168$, $t(63) = 1.35$, or with the size of the easy-hard effect, $r = 0.010$, $t(63) = 0.08$. The size of the easy-hard effect was also examined as a function of PPVT performance bin. Characteristics of PPVT raw scores for each performance bin are shown in Table 3, separately for OC users and TC users. To keep cell sizes reasonably large, PPVT performance was divided into thirds rather than quarters. For OC users, the size of the easy-hard effect from the worst performing to best performing PPVT tertile was, respectively, 11.87, 16.74, and 17.41, a non-significant effect, $F(2,90) < 1$. For TC users, the size of the easy-hard effect from the worst performing to best performing PPVT tertile was, respectively, 16.24, 13.05, and 15.17, also a non-significant effect, $F(2,90) < 1$.

	T1	T2	T3
OC Users			
N	30	31	32
Mean	40.33	70.07	113.34
Standard Deviation	12.43	8.73	25.90
TC Users			
N	21	21	23
Mean	51.29	78.71	123.17
Standard Deviation	8.99	7.62	31.39

Table 3. N, Mean, and Standard Deviations for each of the three PPVT raw score tertiles for OC and TC users used in the MLNT analysis.

Summary of the Effect of Lexicon Size on the Easy-Hard Effect. To the extent that either the LNT and MLNT or the PPVT are legitimate measures of lexicon size, there is no evidence that the size of the easy-hard effect **decreases** as the size of pediatric CI users' lexicons increases. On the contrary, there is some evidence that on the LNT the size of the easy-hard effect increases to a small amount with lexicon size. This effect appears to be limited to OC users. No such effect is evident in the data for TC users. For TC users, the size of the easy-hard effect seems to be fairly constant across difference lexicon sizes. On the MLNT, the size of the easy-hard effect also appears to be constant across different lexicon sizes for both OC and TC users.

Comparing the Easy-Hard Effect with the Word Length Effect

The second issue that we investigated concerned the origin of the word length effect. More specifically, we attempted to determine whether the word-length effect has the same underlying causes as the easy-hard effect. Accordingly, we examined how the word length effect varies with the easy-hard effect. In the overall sample of 213 test intervals for which data were available from both the LNT and MLNT tests, the correlation between the LNT easy-hard effect and the word length effect (MLNT

percent correct minus LNT percent correct) was 0.063, a non-significant relation. The overall correlation between the MLNT easy-hard effect and the word length effect was -.014, also a non-significant relation. In an effort to control for floor and ceiling effects, we repeated these correlations after eliminating all tests on which either LNT or MLNT overall percent correct was below 20% or above 80%. A total of 151 test intervals remained after eliminating these results. For this more restricted sample, the correlation between the LNT easy-hard effect and the word length effect was -0.072, a non-significant relation. The correlation between the MLNT easy-hard effect and the word-length effect was -0.135, a marginally significant **negative** correlation, $t(149) = 1.66$, $p < .10$.

We divided the sample of 151 tests where both LNT and MLNT performance was in the range 21-80% correct into those children using OC (N=91) and those using TC (N=60). For the OC group, the correlation between the easy-hard effect on the LNT and the word length effect was -0.151, $t(89) = 1.44$, n.s., and the correlation between the easy-hard effect on the MLNT and the word length effect was also -0.147, $t(89) = 1.40$, n.s. For the TC group, the easy-hard effect also failed to significantly correlate with the word length effect, $r = 0.077$, $t(58) = 0.59$ for the LNT easy-hard effect, and $r = -0.117$, $t(58) = -0.89$ for the MLNT easy-hard effect.

To examine the question of whether the word length effect changes with lexicon size, changes in the effect with changes in PPVT raw scores were analyzed. The sample of 151 tests in which both LNT and MLNT performance was in the range of 21 to 80% correct included 147 tests which also included PPVT scores. There was no significant correlation between PPVT raw score and the word length effect, $r = 0.059$, $t(145) = 0.71$. Further, no correlation emerged when the data were analyzed separately for OC users, $r = 0.043$, $t(85) = 0.40$, and TC users, $r = 0.105$, $t(58) = 0.80$. Finally, the word length effect did not change significantly as a function of PPVT performance tertile in either the OC group, $F(2,84) < 1$, or in the TC group, $F(2,57) = 1.21$. Across PPVT performance tertile, in the OC group, the word length effect was 7.07, 10.35, and 8.24. In the TC group, the word length effect was 4.73, 9.45, and 8.08 across PPVT tertile.

Summary of Results on the Word Length Effect. In summary, there is little evidence that the easy-hard effect and the word length effect are correlated with one another. In addition, there is little evidence that the word length effect changes with growth in the size of the lexicon.

Comparing OC and TC Users

Our primary interest in comparing OC and TC users was to determine if the two classes of users showed different patterns of easy—hard or word length effects at a given lexicon size. Accordingly, from our master set of test records we selected a sample that matched lexicon size in OC and TC users. We used PPVT raw scores as a measure of lexicon size. From our master group of 443 test records, we first eliminated those for which no PPVT data were available, leaving 152 TC users and 281 OC users. For each test record contributed by a TC child, we then selected a test record contributed by an OC child with an identical PPVT raw score. If no OC child had an identical PPVT raw score, we selected that record with the nearest PPVT raw score. If multiple OC records had an identical PPVT raw score, we chose a record from amongst those with the identical score in a pseudo-random fashion. Records were selected from OC users without replacement. Table 4 shows demographic characteristics of the two groups. Note that TC children were marginally older than OC children, were fitted with a CI implant at a later age, and had a later age of onset of deafness. These characteristics were true of our master sample as well.

	OC	TC
PPVT Raw Score	82.33	82.02
Interval	9.78	9.54
CA	105.25	112.05#
Fitted	46.48	54.41***
Onset	6.95	13.26*

Table 4. Demographics of the OC and TC matched groups. Interval refers to the 6-month period after implant at which the test was conducted. (Interval 1 is 6 months post-implant, interval 2 is 12 months post-implant, and so on.) CA is chronological age, Fitted is age at which the child received the cochlear implant, and Onset is the age at onset of deafness. CA, Fitted and Onset are all in months. #: $p < .10$. * $p < .05$. *** $p < .005$.

Figure 11 shows overall performance of the OC children and TC children on the LNT, separately for easy and hard words. Overall, OC users performed better than TC users on the LNT, $F(1, 302) = 84.46$, $p < .0001$. Percent correct was higher on easy words than on hard words, $F(1,303) = 336.36$, $p < .0001$. The size of the easy—hard effect (15.36 for the OC group; 12.86 for the TC group) was at best marginally larger in the OC group than in the TC group, $F(1, 302) = 2.66$, $p = .10$.

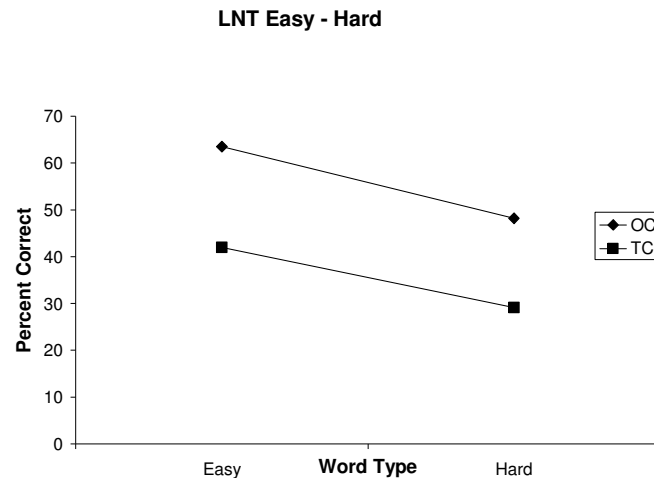


Figure 11. LNT performance as a function of word type (easy vs. hard) for OC users and TC users.

In order to avoid possible misleading results due to floor or ceiling effects, we repeated the above analyses but including only matched records where the overall LNT test score was between 21 and 80 percent correct, inclusive. We began with the 112 TC users who scored in this range and then matched each of those users with an OC user who also scored within that range, using the same matching procedures used for the larger group. Table 5 shows some demographic characteristics of these subgroups. Although the two groups did not significantly differ on chronological age, TC users were fitted with a CI at a later age than OC users and were marginally older at the age of onset of deafness than OC users.

	OC	TC
PPVT Raw Score	86.63	86.45
Interval	10.39	10.13
CA	109.48	115.93
Fitted	47.08	54.74*
Onset	8.36	14.00#

Table 5. Demographics of the OC and TC matched groups who performed between 21% and 80% correct on the LNT. Interval refers to the 6-month period after implant at which the test was conducted. (Interval 1 is 6 months post-implant, interval 2 is 12 months post-implant, and so on.) CA is chronological age, Fitted is age at which the child received the cochlear implant, and Onset is the age at onset of deafness. CA, Fitted and Onset are all in months. #: $p < .10$. * $p < .05$

Figure 12 shows performance on the LNT for these sub-groups. OC users scored higher on the LNT than TC users, $F(1, 222) = 42.64$, $p < .0001$. Percent correct was higher on easy words than on hard words, $F(1, 223) = 326.89$, $p < .0001$. The size of the easy-hard effect for the two groups did not differ, $F(1, 222) < 1$.

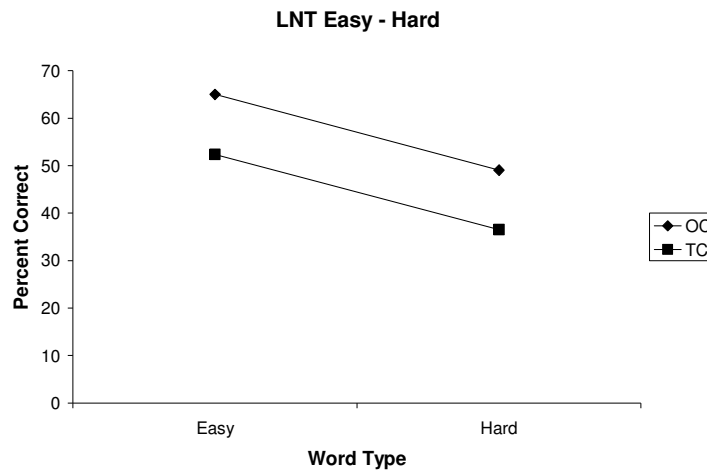


Figure 12. LNT performance as a function of word type (easy vs. hard) for OC users and TC users scoring between 21 and 80 percent correct on the LNT..

As mentioned, our intent had been to control for lexicon size by matching on PPVT raw score. This procedure seemed preferable to matching on LNT percent correct and then examining variations in the easy-hard effect since PPVT raw scores are arithmetically independent of the easy-hard effect but LNT overall performance is not. However, given that the OC children consistently performed at a higher percent correct on the LNT than did the TC children, an argument could be made that, to the extent that the LNT is a better measure of lexicon size than is the PPVT, we had not in fact matched the two sub-groups for lexicon size. Accordingly, we conducted an initial analysis in which we matched OC and TC children on overall LNT percent correct. To avoid spurious results due to floor and ceiling effects, this analysis was limited to those children who scored between 21 and 80 percent correct, inclusive, on overall on the LNT. Because of the overall lower performance of the TC children, it was not possible to match all TC test records with a corresponding OC test record. We first selected for inclusion in this sub-sample all TC test records for which there was an OC test record with an identical overall percent correct

on the LNT. We then selected from the remaining records all those pairs of OC and TC test records within 2% of each other on overall percent correct on the LNT, with the stipulation that for every pair in which the OC record had a higher score, another pair had to be included in which the TC record had the higher score. The final sub-sample consisted of 184 records, 92 from OC children and 92 from TC children.

Table 6 shows some demographic characteristics of this sub-sample, as well as the size of the easy-hard effect for the two CM groups. The important result was that the easy-hard effect for the OC children did not significantly differ from that of the TC children, $F(1, 182) < 1$.

	OC	TC
LNT Percent Correct	47.49	47.49
Interval	9.29	9.93
CA	103.92	113.60#
Fitted	48.55	53.63
Onset	7.25	15.27*
Easy-Hard Effect	14.89	15.86

Table 6. Demographics of the OC and TC matched groups who performed between 21% and 80% correct on the LNT. These groups were matched on overall LNT Percent Correct. Interval refers to the 6-month period after implant at which the test was conducted. (Interval 1 is 6 months post-implant, interval 2 is 12 months post-implant, and so on.) CA is chronological age, Fitted is age at which the child received the cochlear implant, and Onset is the age at onset of deafness. CA, Fitted and Onset are all in months. #: $p < .10$. * $p < .05$

We performed a similar set of analyses on the MLNT data, beginning with an analysis where we matched records based on PPVT raw scores. For those children who contributed MLNT data, we matched each TC child with an OC child using the same procedure as used for the LNT data. Each resulting sub-group had a total of 83 test records. Table 7 shows some demographic characteristics of this group. Figure 13 shows the percent correct of these children on the MLNT, broken down by CM and Easy and Hard words. The MLNT results paralleled those for the LNT. OC children correctly identified more words on the MLNT than did the TC children, $F(1, 164) = 28.09$, $p < .0001$. Easy MLNT words were identified correctly more frequently than hard MLNT words, $F(1, 165) = 108.62$, $p < .0001$. The size of the easy-hard effect did not differ significantly between the two CM groups, $F(1, 164) < 1$.

	OC	TC
PPVT Raw Score	83.93	83.83
Interval	9.35	9.42
CA	110.64	113.35
Fitted	54.36	56.25
Onset	7.02	18.66***

Table 7. Demographics of the OC and TC MLNT groups matched on PPVT raw scores. Interval refers to the 6-month period after implant at which the test was conducted. (Interval 1 is 6 months post-implant, interval 2 is 12 months post-implant, and so on.) CA is chronological age, Fitted is age at which the child received the cochlear implant, and Onset is the age at onset of deafness. CA, Fitted and Onset are all in months. *** $p < .005$.

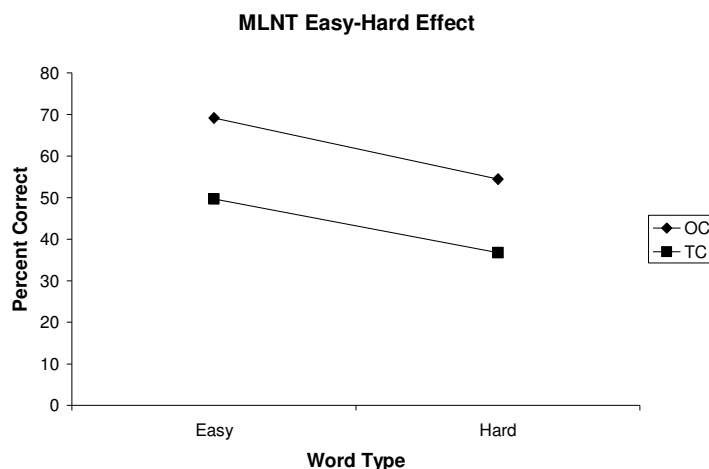


Figure 13. Percent correct for easy and hard MLNT words for OC and TC users matched on PPVT scores.

Figure 14 shows the word length effect for these two sub-groups. Overall, percent correct was higher on the MLNT than on the LNT, $F(1, 330) = 9.18, p < .005$. Although this word length effect was slightly larger in the OC group than in the TC group, the difference was not statistically significant, $F(1, 164) = 1.53$.

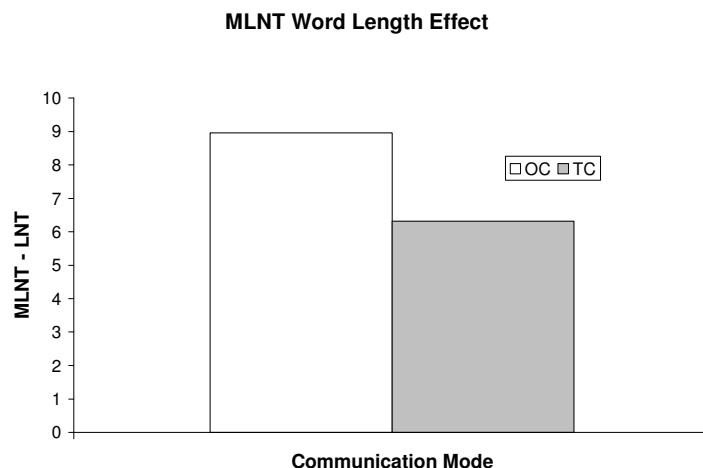


Figure 14. Word length effect for OC and TC users matched on PPVT scores.

Following the same rationale as for the LNT tests, we also matched MLNT test records on LNT scores instead of PPVT scores, following the same procedure as for LNT scores. This procedure resulted in 63 test records in the OC group and 63 in the TC group. Demographic characteristics of this sub-group, as well as the word length effect, are shown in Table 8. When matched on LNT performance, OC children did not score significantly higher on the MLNT than did TC children, $F(1, 124) < 1$. Easy words were identified more accurately than hard words, $F(1, 125) = 77.79, p < .001$. The size of the easy-hard effect on the MLNT, however, did not differ significantly between the two CM groups, $F(1, 124) = 1.10$. Overall, percent correct was higher on the MLNT than on the LNT, $F(1, 250) = 10.18, p < .005$.

Although this word length effect was slightly larger in the OC group than in the TC group, the difference was not statistically significant, $F(1, 124) = 1.10$.

	OC	TC
LNT Percent Correct	40.48	40.51
Interval	49.78	54.03
CA	105.79	111.92
Fitted	56.02	57.89
Onset	5.62	21.51***
Word Length Effect	10.01	7.96

Table 8. Demographics of the OC and TC groups contributing MLNT data and matched on overall LNT percent correct. Interval refers to the 6-month period after implant at which the test was conducted. (Interval 1 is 6 months post-implant, interval 2 is 12 months post-implant, and so on.) CA is chronological age, Fitted is age at which the child received the cochlear implant, and Onset is the age at onset of deafness. CA, Fitted and Onset are all in months. *** $p < .001$.

We also analyzed the MLNT data matched on LNT scores after eliminating all pairs of test records in which either the OC record or the TC record had an LNT percent correct outside the range of 21-80, inclusive. The two resulting sub-groups each had 50 test records. This manipulation did not change the basic pattern of results. Overall percent correct on the MLNT did not differ between OC and TC children, $F(1, 98) < 1$. MLNT easy words were identified more accurately than hard words, $F(1, 99) = 166.05$, $p < .001$. The size of the easy-hard effect, however, did not differ significantly between the two CM groups, $F(1, 98) < 1$. Overall, percent correct was higher on the MLNT than on the LNT, $F(1, 198) = 20.79$, $p < .0001$. Although this word length effect was slightly larger in the OC group (Mean = 11.16) than in the TC group (Mean = 9.43), the difference was not statistically significant, $F(1, 98) < 1$.

Summary of Results on Communication Mode. OC children and TC children both show robust easy—hard and word length effects. When test records are matched on lexicon size, the size of these effects does not significantly differ across users of the two communication modes. When PPVT is used to match on lexicon size, OC children perform better than TC children on both the LNT and MLNT.

Discussion

The main results of the present study can be summarized as follows:

First, for OC users, the size of the easy-hard effect on the LNT increases, albeit by a small amount, as lexicon size increases. The increase occurs regardless of whether lexicon size is measured by LNT overall percent correct or PPVT raw scores. In contrast, for TC users, the size of the easy—hard effect does not change as lexicon size increases.

Second, unlike the results for the LNT, the size of the easy-hard effect on the MLNT does not change as lexicon size increases for either OC or TC users. This result holds regardless of whether lexicon size is measured by overall LNT percent correct or by PPVT raw scores.

Third, the size of the easy-hard effect does not significantly correlate with the size of the word length effect for either OC users or TC users.

Fourth, the size of the word length effect does not appear to change as lexicon size increases, for either OC users or TC users, where lexicon size was measured by PPVT raw scores.³

Fifth, when matched on PPVT raw scores, OC children perform better than TC children on both the LNT and MLNT.

We begin by first attempting to explain the pattern of results concerning the easy-hard effect. Suppose that CI children assume that what they are hearing in the LNT (and MLNT) are spoken words, and that they therefore repeat back the closest matching word in their lexicon. Suppose further that, due to the acoustic “noise” introduced by the CI, CI children begin with relatively undifferentiated, coarse phonetic representations. Many words that are similar sounding yet clearly different words to an adult normal hearer are in fact mapped to the same representation in the mental lexicon of CI users. The CI user, for instance, might map the words /kæt/, /kæp/, and /kæn/ to a single representation, say that corresponding to /kæp/. When presented with any of these three words in a word repetition task, the child will respond with /kæp/. Note that this process essentially amounts to a guessing strategy. Such a guessing strategy is more likely to be correct for words with few phonetically similar words (i.e., easy words) than for words with many phonetically similar words (i.e., hard words). The result is a robust easy-hard effect. Over time, as the child gains experience with the CI, finer phonetic discriminations are learned and the mental lexicon becomes correspondingly more differentiated. The words /kæt/ and /kæp/ may still map to the same lexical representation, but the word /kæn/ now maps to its own representation. In effect, on a word repetition task, the child is now guessing from amongst fewer alternatives, resulting in overall improved performance. When a new discrimination is learned, it is more likely to split a group of hard words into two smaller equivalence classes than it is to split a group of easy words into two smaller groups, simply because the group of hard words is larger to begin with. The result is that a) overall lexicon size should appear larger since the child is making more phonetic discriminations, and b) performance on hard words should improve faster than performance on easy words. Thus, as lexicon size increases, the size of the easy-hard effect should decrease. This prediction is clearly inconsistent with our data.

An alternative perspective may make these data more comprehensible. While the child’s lexicon is developing, it may simply be the case that many words that in the more mature lexicon would have multiple neighbors have in fact many fewer neighbors. Statistically, the less mature lexicon, with fewer overall words, is likely to show reduced neighborhood density differences between easy and hard words. This reduction in turn would mitigate easy-hard effects. As the lexicon grows in size and connectivity, so do neighborhood density differences and therefore so does the easy-hard effect. That is, the easy-hard effect should increase as the size of the mental lexicon increases. This prediction is consistent with our findings for OC children on the LNT.

This second alternative can be stated somewhat differently. The key insight of word recognition models such as those proposed by Luce and Pisoni (1998) and Auer and Luce (2005) is that words are recognized in the context of other, similar sounding words. According to these models, a listener’s mental lexicon is organized into similarity neighborhoods of interconnected words, with some neighborhoods being more densely populated than others. The easy-hard effect is a consequence of this organization into similarity neighborhoods. To the extent that a listener has no interconnections among the words in the lexicon, no easy-hard effect emerges. As those lexical connections develop and become

³ Parallel analyses using overall LNT percent correct as a measure of lexicon size were not performed. Since the word length effect is defined as MLNT percent correct minus LNT percent correct, there will be a tendency for a negative correlation to emerge with LNT even if MLNT and LNT performance are completely independent.

richer, the mental lexicon organizes itself into similarity neighborhoods and easy-hard effects emerge. Hence, larger easy-hard effects would be expected as the CI user's lexicon matures.

Why then is the increase so small and limited to OC children on the LNT? The answer to the second part of the question—why the increase is limited to OC children—may well be that only these children, because they rely much more on phonetic information for language communication, form the more richly interconnected lexical space necessary for similarity neighborhoods, and hence easy-hard effects, to emerge. The answer to the first part of the question—why the increase is so small—may well be that both the above alternatives may be operating, with observed performance simply the averaged effects of these two opposing processes. Increased phonetic differentiation may be causing decreased easy-hard effects while growth in lexicon size is causing increased easy-hard effects. To the extent that the two opposing trends are of approximately equal magnitude, they cancel one another out and the overall effect is little or no change in the easy-hard effect as the lexicon grows.

There is one aspect of our data which is not, at least superficially, entirely consistent with this hybrid proposal. In particular, it is only with OC children that we observed an increased easy-hard effect, indicating that growth in lexicon size was playing a larger role with them than phonetic differentiation. However, since it is precisely OC children who in their daily lives are presumably forced to make greater use of auditory cues for spoken word recognition, it is precisely these children that we would expect to show increased phonetic differentiation and hence smaller easy-hard effects, since words like /kæt/ and /kæp/ would now have separate representations. Similarly, when we matched OC and TC users on overall LNT percent correct or PPVT raw scores, we might have expected reduced easy-hard effects in the OC group. It is, of course, possible that by the time we began testing these children, the OC users' powers of phonetic discrimination were already relatively advanced. Consequently, these children were in fact more likely to show the effects of a growing lexicon. There is, however, nothing in our data that would support this *ad hoc* explanation.

There is a second limitation to this hybrid proposal. It posits a coincidence (The two effects just happen to nearly balance one another out.) and it runs the risk of non-falsifiability (In any given study, any pattern of change in the easy-hard effect could be explained by appealing to different strengths of the two processes.). Clearly, before it can claim to have received strong support, additional research is necessary that attempts to tease apart the two effects. Do, for example, children who show a poor ability to discriminate phonemes (as measured, for example, by performance on an ABX discrimination task using minimal-pair nonsense syllables) also show larger easy-hard effects?

Our second group of results concerns the word length effect and its relation to the easy-hard effect. Like the easy-hard effect in most cases, the word length effect did not show significant change as the size of the lexicon grew. The more important result is that the easy-hard effect and the word length effect do not correlate with one another. That these two effects appear independent of one another suggests that they have different causes. Easy words come from sparser neighborhoods than hard words and neighborhood density is thought to at least in part account for the easy-hard effect (e.g., Kirk et al., 1995). Longer words also come from sparser neighborhoods than shorter words. Hence, neighborhood density could also underlie the word length effect. That it is independent of the easy-hard effect, however, suggests that we may need to look elsewhere than density for an explanation of the word length effect. The obvious alternative is that the CI users are sensitive to the syllabic structure of words, and use the number of syllables as a word recognition cue, at least when identifying isolated words. Because there are fewer multi-syllabic words than monosyllabic words in the child's lexicon, (Logan, 1992), knowing the number of syllables in the word limits possible identifications to a smaller universe for

longer words than it does for shorter words. The result would be better performance in recognizing multi-syllabic words, independent of neighborhood density.

The final result meriting comment concerns the finding that, when OC and TC children are matched on PPVT scores, the OC children outperform the TC children on both the LNT and the MLNT. These results are reminiscent of those of Sommers et al. (1997). One obvious difference between the PPVT, on the one hand, and the LNT and MLNT on the other hand is that the PPVT is a closed-set task whereas the LNT and MLNT are both open-set tasks. Sommers et al. found that normal hearing adults listening in the clear, normal hearing adults listening under conditions of noise, and adult CI users all showed effects of talker variability (identifying words in lists with multiple talkers compared to identifying words in lists spoken by a single talker) and lexical difficulty (easy words and hard words as defined here) only on open-set tasks. Closed set tasks were not sensitive to these manipulations even when the response alternatives were designed to be maximally similar to the correct response. These results were recently confirmed by Clopper, Tierney, and Pisoni (2003) under somewhat different listening conditions. A similar effect is likely happening in the present study. The closed-set PPVT is simply not sensitive enough to reveal differences between the OC and TC populations of CI users. This result emphasizes the importance of including open-set tasks in test batteries investigating differences in the ability of different CI user populations in identifying spoken words.

In summary, we found some evidence that for OC users the size of the easy-hard effect on the LNT increases as the size of the child's lexicon increases. This result could reflect increased connectivity in the child's lexicon. As the lexicon grows, similarity neighborhoods begin forming and neighbors begin competing with one another for recognition. This result was not apparent for TC users. Likewise, we found little or no change in the easy-hard effect on the MLNT as lexicon size increased, and little or no change in the size of the word length effect. Overall, both the size of the easy-hard effect and the size of the word length effect seem remarkably stable over a wide range of lexicon sizes.

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