Suprasegmental aspects of pre-lexical speech in cochlear implanted children

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Abstract

This paper investigates suprasegmental features in the pre-lexical speech of congenitally hearing impaired children who received a Nucleus-24 multichannel cochlear implant between 5 and 20 months of age. Bi-syllabic spontaneous babbling productions were analyzed acoustically at different stages in the babbling period. Fundamental frequency, pitch change in terms of direction and degree, and duration were analyzed for each vowel. The results were compared with those of a control group of normally hearing children, and analyzed with respect to length of cochlear implant experience. Few differences were found between the normally hearing children and the cochlear implanted children in terms of suprasegmental aspects, indicating that a cochlear implant provides fundamental improvement already in pre-lexical speech. Nevertheless, differences in pitch variations between the two groups of children at the end of the babbling period may signify a weakness related to the cochlear implant.

Index terms: cochlear implant, children, babbling, suprasegmentals

1. Introduction

Detailed studies regarding the segmental characteristics of babbling of hearing impaired children with a cochlear implant recently appeared [5, 6, 15]. Little attention has been paid to the suprasegmental aspects of these children's babbling. In this study, we analyze certain suprasegmental features in the babbling of a unique group of young congenitally hearing impaired children who received a cochlear implant before the age of 20 months.

There is a general agreement that auditory feedback is an important cue in the speech development, and that the lack of auditory feedback, and therefore the lack of fine control of the voice, affects the suprasegmental characteristics of voice and speech. This issue has been studied throughoutly during the last years; deviant suprasegmental features have been found in the speech, and even in the babbling, of hearing impaired children. The most prominent suprasegmental characteristics of hearing impaired babbling and speech are slow speaking rate [2, 3, 12], high fundamental frequency [4, 7, 8], large amounts of utterances with pitch variation and greater pitch variation within utterances [2, 8].

Formal studies focusing on the suprasegmental characteristics of the babbling of congenitally hearing impaired children with a cochlear implant are, to our knowledge, non-existing. A number of studies analyzing the speech production of older cochlear implant children have been carried out. The majority of these studies, though, are based on elicited speech, and not on spontaneous speech. The general suprasegmental trends reported, are slow speaking rate [13], post-operative decrease of F0, which gives normal mean pitch values after implantation [10], unsatisfactory production of rising intonation [18], deviant rhythm and monotone stress pattern [11]. Age at implantation and cochlear implant experience seem to have positive effects on the prosody [11, 16, 17]. Although similar trends are found for the speech of HI children and CI children, it seems that some of the suprasegmental features in the speech of CI children are different from those typically observed in children with severe to profound hearing impairments. The findings suggest that cochlear implants offer some significant benefits to children with hearing impairment in terms of prosody, but that the access to the auditory information needed for certain suprasegmental features may be limited. Early age at implantation seems to have a positive effect on the speech performance of the CI children, as well as cochlear implant experience. The present study evaluated temporal aspects and pitch patterns in spontaneous pre-lexical productions of CI children compared to NH controls. Does auditory exposure already in the prelinguistic stage enable the CI children to produce babbling with similar suprasegmental features as NH children? Will we find deviant features as reported in the babbling and speech of hearing impaired children? The results will show us whether, and in which degree, deviant suprasegmental features are visible already in the pre-lexical speech of these early implanted children and whether length of CI experience influences these features.

2. Method

2.1. Subjects

Ten congenitally hearing impaired children of Dutch-speaking hearing parents participated in this study. The children had an average unaided hearing loss of more than 90 dBHL in the better ear. The children received a multichannel Nucleus-24 cochlear implant between 5 and 20 months of age. Five of the children were implanted in their first year of life (5-10 months), and five in their second year of life (13-20 months). The PTA with CI was between 32 and 47 dBHL. The children received oral education, with or without the support of basic Dutch signs. 9 normally hearing children of Dutch-speaking hearing parents participated as control group. These children were followed up from 6 months onwards.

2.2. Data collection

The details of the data collection were published earlier [14]. Briefly, monthly video recordings of approximately 60-80 minutes spontaneous parent-child interaction were carried out in the children's homes. A 20 minutes sample was selected from each recording. The sampling procedure was done by one person and aimed at selecting delineated sequences of interaction. The vocalizations were coded in terms of phonation and articulation according to the model proposed by Koopmans-van Beinum & van der Stelt **[9]**. Babbling was defined as multiple articulatory movements in one breath unit combined with continuous or interrupted phonation. For this study, two stages at the beginning and the end of the babbling period were selected: 1) The ‘Babble spurt stage’, defined as a sudden increase of babbled productions, and 2) The ‘Ten word stage’, defined as production of at least 10 different word types. For the identification of words, the procedure articulated by Vihman & McCune [19] was followed. All bi-syllabic babbling productions were selected for acoustic analysis; in total 1222 vowels were analyzed from the 611 bi-syllabic productions. Table 1 shows the number of vowels per child group and age. Babbling productions containing simultaneous speech, background noise from toys, television and radio were excluded, as were any babbling productions with a lack of periodic vibrations of the vocal cords.

	CI	NH	total
Babble spurt stage	244	226	470
Ten word stage	362	390	752
Total	606	616	1222

Table 1. Number of vowels analyzed for each child group and age.

2.3. Acoustical analysis procedures

Each bi-syllabic babbling production was analyzed in Praat version 4.4.03 **[1]**. We assessed the following suprasegmental parameters for each vowel: (1) duration, (2) fundamental frequency and (3) pitch change in terms of direction and degree. The beginning of the babbling production was defined as the first glottal pulse in the first syllable. The end of the babbling production was defined as the last visible glottal pulse of the last syllable. The consonant-vowel boundary was set between the visible lingual closure and the vowel in the spectrogram, at the first glottal pulse by the opening for the vowel, at the point where formants became visible. The termination of the vowel in open syllables was set at the point of loss of audible signal. The mean fundamental frequency of the vowel was extracted through the autocorrelation algorithm in PRAAT. The pitch floor was set to 150 Hertz and the pitch ceiling to 800 Hertz, based on pre-tests of the data.

To calculate the pitch direction and degree of pitch change within the vowel, each vowel was first divided into three parts by means of a script. Secondly, the mean pitch of the initial part of the vowel and the mean pitch of the final part of the vowel were measured. Thirdly, the pitch difference was calculated as the mean pitch of the final part of the vowel minus the mean pitch of the initial part of the vowel. A negative value (<-5 Hz) was labeled as a falling pitch direction, and a positive value (>5 Hz) as a rising pitch direction. When the value was within the range –5 Hz to +5 Hz, the vowel was labeled as ‘steady’. The value of the pitch difference indicates the degree of pitch change; a low value means a small pitch change, while a large value means a large pitch change. For all variables, the values were first averaged per child. Then non-parametric descriptive and analytical statistics were applied to analyze the group results (10 children in the CI group and 9 in the NH group). For all tests, the cut-off level of significance was set at $p=0.05$.

3. Results

3.1. Vowel duration

The initial vowels (V1) in the bi-syllabic productions were found to have shorter durations than the final vowels (V2) for both CI children as well as NH children, though the difference was only significant for the NH children (Wilcoxon test, $p=0.02$, V1=238.73 ms, V2=296.20 ms at ‘Babble spurt stage’; $p=0.02$, V1=190.04 ms, V2=293.98 ms at ‘Ten word stage’). Due to these differences in duration, V1 and V2 were hence analyzed separately. Figure 1 is a plot of the vowel durations for V1 per child group and age. Figure 2 is a plot of the vowel durations for V2 per child group and age.

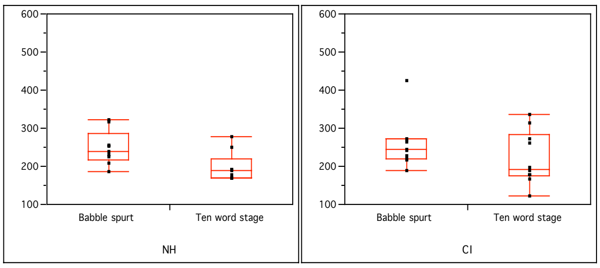

Figure 1. Median duration (ms) for V1 per child group (NH - CI) and age (Babble spurt stage - Ten word stage).

A Wilcoxon test indicated a significant decrease in initial vowel duration over age for the NH children ($p=0.02$, median durations 239 ms at ‘Babble spurt stage’ and 190 ms at ‘Ten word stage’). A similar trend towards a decrease in vowel duration over age was seen for CI children, but, probably due to large inter-individual variations in duration at ‘Ten word stage’, the differences in duration were not significant (median durations 244 ms at ‘Babble spurt stage’ and 193 ms at ‘Ten word stage’).

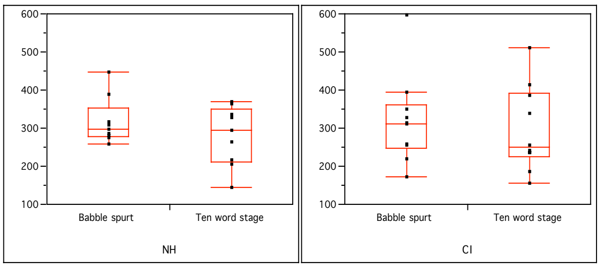

Figure 2. Median duration (ms) for V2 per child group (NH - CI) and age (Babble spurt stage - Ten word stage).

Large inter-individual variations in durations were found for the final vowels (fig. 2). The data for the final vowels show no statistical differences between the ‘Babble spurt stage’ and the ‘Ten word stage’, neither for the NH group (296 ms and 294 ms respectively) nor for the CI group (312 ms and 249 ms respectively). No statistical differences were found between the NH and the CI group.

3.2. Fundamental frequency

The initial and final vowels in the bi-syllabic productions did not show any significant differences in fundamental frequency, which allowed us to pool all the vowels for further analysis.

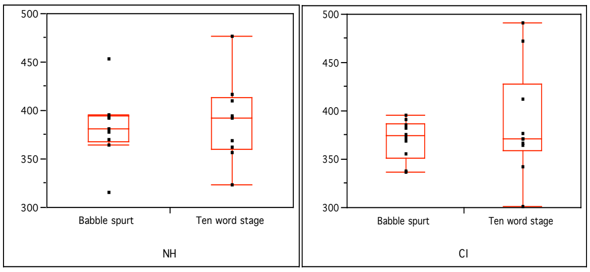

Figure 3. Median fundamental frequency (Hz) for V1+V2 per child group (NH - CI) and age (Babble spurt stage - Ten word stage).

Large inter-individual differences in fundamental frequency were found for both NH as well as CI children at ‘Ten word stage’. No statistical differences between the ‘Babble spurt stage’ and the ‘Ten word stage’ were found; neither for the NH group (381 Hz and 393 Hz respectively) nor for the CI group (374 Hz and 371 Hz respectively). No statistical differences were found between the NH and the CI group.

3.3. Direction of pitch change

The distribution of ‘falling’, ‘rising’ and ‘steady’ pitch change within each vowel was analyzed per child group and age. The majority of the vowels were produced with pitch change; i.e. falling or rising pitch. The amount of vowels with absence of pitch change, i.e. ‘steady’ pitch, was never in majority for any of the children. The distribution of ‘steady’ pitch productions is illustrated in figure 4.

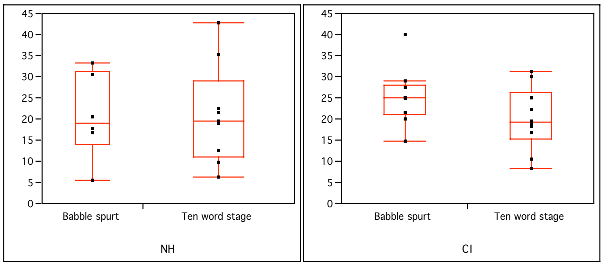

Figure 4. Amount of ‘steady’ vowels (in percentage) for V1+V2 per child group (NH - CI) and age (Babble spurt stage - Ten word stage).

Figure 4 shows that roughly 20 % of all vowels had absence of pitch change (steady) and 80 % had presence of pitch change (either rising or falling), both at the beginning and at the end of the babbling period. Although none of the differences were statistically significant, it is remarkable that CI children tend to produce a larger amount of steady vowels in the beginning of their babbling period (25 %) compared to the end (19 %).

3.4. Degree of pitch change

All vowels with presence of pitch change (falling and rising) were pooled, and the absolute numbers were used to analyze the degree of pitch change within the vowels.

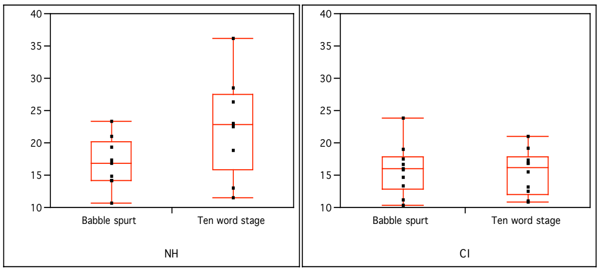

Figure 5. Median degree of pitch change (Hz) within the vowel for V1+V2 per child group (NH - CI) and age (Babble spurt stage - Ten word stage).

When producing pitch change, NH children demonstrate significantly stronger pitch variations than CI children at the end of the babbling period (NH: median $\Delta F0$ = 22.83 Hz; CI: median $\Delta F0$ = 16.17 Hz). No difference between the NH and CI was observed at the beginning of the babbling period (NH: median $\Delta F0$ = 16.82 Hz; CI: median $\Delta F0$ = 15.97 Hz). While NH children tend to produce stronger pitch variations at the end of the babbling period than at the beginning of the babbling period, no changes over age were observed for the CI children. Moreover, no statistical differences were found between the children implanted before and after one year of age.

4. Conclusions

The initial question was whether deviant suprasegmental features are visible already in the pre-linguistic babbling of CI children and whether length of CI experience influences these features. Pitch patterns and durations were analyzed for 1222 pre-lexical vowels in bi-syllabic productions of NH and CI children. There were no statistical differences in vowel duration between the NH and the CI children, neither at the beginning nor at the end of the babbling period. The durational values of the initial vowels in the bi-syllabic babbling productions show that the NH children produce significantly shorter initial vowels, as they get older. The same development has only been observed as a trend for the CI children. This suggests that some CI children have problems with the strict canonical syllable form. No differences in fundamental frequency were observed between the NH children and the CI children. These results indicate that fundamental frequency is not a problematic feature for the CI children, and that they, unlike HI children reported in other studies, control the fundamental frequency as NH children do already in pre-lexical speech. Although a trend for preference for ‘steady’ vowels could be observed for the CI children at ‘Babble spurt stage’, this trend was no longer visible at ‘Ten word stage’. This shows that the CI children develop in the same way as the NH children do, with a preference for vowels with pitch variation. Even though the CI children develop towards the NH children regarding the amount of vowels produced with pitch variation, they do not seem to follow the NH children in the *degree* of pitch change. While the degree of pitch change increases over age for the NH children, and they produce vowels with a large degree of pitch variation at the end of the babbling period, the CI children do not seem to follow this development. Neither cochlear implant experience nor age at implantation had any positive effects on the degree of pitch change. This difference between NH and CI children may be due to limitations in the cochlear implant, or due to the hearing impairment itself, which, despite good audiological input, is not fully recuperated. In summary, the data presented in this study show that there are few differences in the babbling of NH and CI children on suprasegmental level. No statistical differences were found in fundamental frequency, direction of pitch change or duration between the two groups of children. Statistical differences were found in degree of pitch change; where NH children produced vowels with a stronger pitch variation at the end of the babbling period than CI children.

A cochlear implant, provided it is given early enough, has shown to deliver hardly any differences in the pre-lexical speech of NH and CI children on segmental level [15]. The present study shows parallel results on suprasegmental level, indicating that a cochlear implant provides fundamental improvements also for suprasegmental features in pre-lexical speech.

5. References

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