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Hearing impairment and vowel production. A comparison between normally hearing, hearing-aided and cochlear implanted Dutch children

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ABSTRACT

This study investigated the acoustic characteristics of the Belgian Standard Dutch vowels in children with hearing impairment and in children with normal hearing. In a balanced experimental design, the 12 vowels of Belgian Standard Dutch were recorded in three groups of children: a group of children with normal hearing, a group with a conventional hearing aid and a group with a cochlear implant. The formants, the surface area of the vowel space and the acoustic differentiation between the vowels were determined. The analyses revealed that many of the vowels in hearing-impaired children showed a reduction of the formant values. This reduction was particularly significant with respect to *F*2. The size of the vowel space was significantly smaller in the hearing-impaired children. Finally, a smaller acoustic differentiation between the vowels was observed in children with hearing impairment. The results show that even after 5 years of device use, the acoustic characteristics of the vowels in hearing-assisted children remain significantly different as compared to their *NH* peers.

1. Introduction

It is well known that restricted auditory feedback has a negative impact on spoken language. As a result speech production in individuals with hearing impairment is deviant in several respects and appears less intelligible (Abberton, Hazan, & Fourcin, 1990; Monsen, 1976a,b). At a suprasegmental level several prosodic problems have been reported such as a slower speaking rate with laboured articulation, more frequent pauses that are generally longer, monotone intonation with higher than normal pitch levels and the distortion of suprasegmental timing effects (Osberger & McGarr, 1982). At the segmental level, errors in the production of consonants and vowels have been observed. Although these aspects have been

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well documented for different groups of speakers with hearing impairment separately, careful direct comparisons of the speech characteristics of different groups of speakers with hearing impairment are only beginning to emerge. This study was therefore conceived to investigate the acoustic speech characteristics in three groups of speakers differing in hearing status i.e. a group of children with a conventional hearing aid (*HA*), a group with a cochlear implant (*CI*) and a group of children with normal hearing (*NH*). The focus of this investigation is on the acoustic characteristics of the vowels.

It is now well established that the speech characteristics of hearing impaired speakers differ in various ways from those of listeners without hearing impairment, both in adults and in children. In children with a conventional hearing aid, the segmental level of speech is characterized by the distortion of both vowels and consonants. Common problems in the articulation of consonants involve voicing errors (voiceless sounds become voiced and vice versa) and place of articulation substitution errors typically associated with sounds that are articulated posteriorly in the oral cavity where articulatory gestures are less visible. In addition, consonant omission errors have been documented: in some studies word-initial consonant omission appears most frequently (Hudgins & Numbers, 1942), while in others consonant deletion was predominantly word-final (Markides, 1970; Nober, 1967; Smith, 1975). Furthermore, errors pertaining to consonant clusters have been noted and these mainly resulted in errors within clusters by either the omission of one of the consonants in the cluster or by the insertion of schwa (e.g., Baudonck, Dhooge, D'haeseleer, & Van Lierde, 2010).

The articulation of vowels also seems impaired, be it altogether less frequently than that of consonants. In children with a conventional aid several types of errors have been documented. Vowel substitutions are common and the findings suggest that back vowels are produced more correctly than front vowels and open vowels are more often correct than vowels with a closer degree of stricture (Geffner, 1980; Smith, 1975; Slovenian: Ozbic & Kogovsek, 2008, 2010). Nevertheless, the fronting of back vowels has also been reported (Stein, 1980). Another frequent error involves the neutralization of the peripheral vowels, i.e. the reduction of vowels to a more schwa-like quality (Markides, 1970; Smith, 1975). Furthermore, there have been reports of inappropriate vowel nasalization (Stevens, Nickerson, Boothroyd, & Rollins, 1976) and the diphthongization of monophthongs (Markides, 1970; Smith, 1975).

From an acoustic point of view, the vowel space of individuals with a conventional hearing aid is often described as reduced and vowel reduction seems to pertain to both formant frequencies *F*1 and *F*2. This is consistent with the perception of vowels as more centralized, less differentiated and with a significant degree of overlap between the various vowels in the vowel space (Angelocci, Kopp, & Holbrook, 1964; Monsen, 1976a,b; Nicolaidis & Sfakiannaki, 2007; Osberger, 1987; Ryalls, Larouche, & Giroux, 2003; Smith, 1975).

As far as the vowel characteristics in children with a cochlear implant are concerned, it has been found that cochlear implantation leads to a greater differentiation of the vowel inventory (Ertmer, 2001). However, research findings regarding the acoustic characteristics are equivocal. The vowel space of children with a *CI* has been described as significantly reduced as compared to *NH* children's vowel space (Horga & Liker, 2006; Ibertsson, Willstedt-Svensson, Radeborg, & Sahlen, 2008; Liker, Mildner, & Sindija, 2007; Löfqvist, Sahlen, & Ibertsson (2010); Neumeyer, Harrington, & Draxler, 2010). Other reports suggest that the vowel space of *CI* children is broadly similar to that of *NH* children (Ertmer, 2001; Uchanski & Geers, 2003). Baudonck, Van Lierde, Dhooge, and Corthals (2011) did not find any significant differences in the vowel space delineated by the point vowels of Dutch. The main difference between *NH* and *CI* children concerned the significantly larger intrasubject variability in the formant values of the *CI* children. Thus, individual *CI* children's vowel productions are much more variable than those of *NH* children. A similar significantly larger intrasubject variability in the formant values of *CI* children has also been found earlier for profoundly hearing-impaired children (Okalidou, 1996).

The contradictory findings with respect to the entire vowel space are also apparent from specific *F*1 and *F*2 values of individual vowels. Some reports mention an approximation of *CI* children's formant values to those of *NH* children (Kunisue, Fukushima, Nagayasu, Kawasaki, & Nishizaki, 2006). Uchanski and Geers (2003) specifically studied the *F*2 values of the English vowels and found that the *CI* children's values were in the range of the formant values of *NH* children. Baudonck et al. (2011) reported similar results for Dutch. However, Liker et al. (2007) measured significant differences for the *F*2 values of Croatian speaking *CI* children, resulting in the fronting of the whole vowel space. The latter was not found by Baudonck et al. (2011) in their study of Dutch-speaking children. Findings of different studies on vowel *F*1 are much less contradictory: *CI* children's *F*1 values are not significantly different from those of *NH* children (Baudonck et al., 2011) although they tend to be lower (Liker et al., 2007).

Although it can be concluded that vowel production in both hearing-aided and cochlear implanted children is deviant in various respects, it remains difficult to draw valid conclusions about similarities and differences between both groups of children. This requires a careful comparison between cochlear implant and hearing-assisted children with respect to age-matched children with *NH*. Studies of this kind are presently only beginning to emerge, as exemplified by Baudonck et al. (2011) who investigated the acoustic characteristics of the three point vowels /i/, /u/ and /a/ in Belgian Standard Dutch in a group of prelingually deaf children using a cochlear implant ($n = 40$), a group of severely hearing-impaired children with a conventional hearing aid ($n = 34$) and a group of children with normal hearing ($n = 42$). Children took part in an articulation test and for each child 10 tokens of each point vowel were subjected to an acoustic analysis to provide information about *F*1 and *F*2, intrasubject formant variability, intervowel distance along the *F*1:*F*2 axis and surface area of the vowel space. The vowels were taken either from monosyllables or from the stressed syllable of disyllabic words. From the results it appeared that the vowel productions in the *CI* group did not differ significantly from the *NH* group in terms of any of the formant frequencies. The main difference between the *CI* and *NH* group pertained to the intrasubject variability in formant values which is significantly higher in *CI* children. The results also suggested that the vowels in *HA* children mainly differed from the