International Journal of Pediatric Otorhinolaryngology 79 (2015) 541–545

Contents lists available at ScienceDirect

International Journal of Pediatric Otorhinolaryngology

journal homepage: www.elsevier.com/locate/ijporl

Nasalance and nasality in children with cochlear implants and children with hearing aids

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ARTICLE INFO

Article history:
Received 15 June 2014
Received in revised form 20 January 2015
Accepted 22 January 2015
Available online 29 January 2015

Keywords:
Nasalance
Nasality
Cochlear implants
Hearing aids
Children

ABSTRACT

Objectives: In prelingually deaf children, many speech production aspects including resonance, are known to be problematic. This study aimed to investigate nasality and nasalance in two groups of prelingually hearing impaired children, namely deaf children with a cochlear implant (CI) and moderate-to-severely hearing impaired hearing aid (HA) users. The results of both groups are compared with the results of normal hearing children. Besides, the impact of the degree of hearing loss was determined.
Methodology: 36 CI children (mean age: 9;0 y), 25 HA children (mean age: 9;1 y) and 26 NH children (mean age: 9;3 y) were assessed using objective assessment techniques and perceptual evaluations in order to investigate the nasal resonance of the three groups. Ten HA children had thresholds above 70 dB (range: 91 dB–105 dB) and fifteen below 70 dB (range: 58 dB–68 dB). The Nasometer was used for registration of the nasalance values and nasality was perceptually evaluated by two experienced speech therapists using a nominal rating scale (consensus evaluation).
Results: For nasal stimuli, both CI children and HA children showed lower nasalance values in comparison with NH children. The opposite was observed for the oral stimuli. In both hearing impaired groups, cul-de-sac-resonance was observed on a significantly larger scale than in the NH group, and the HA children were judged to be significantly more hypernasal in comparison with NH children.
Conclusions: Despite the fact that a substantial number of the CI and HA children demonstrate normal (nasal) resonance quality, this aspect of speech production is still at risk for hearing impaired children.

1. Introduction

In prelingually deaf children, many speech production characteristics are known to be problematic. In addition to articulation and voice [1–3], the resonance is often a problem in the speech of prelingually deaf children. Gold [4] even stated that the most frequently mentioned problem of deaf speech is related with nasality. While Wilson [5] described hyponasality as an audible characteristic in the speech of hearing impaired children, many other studies concluded hypernasality as a commonly perceived characteristic [6–11]. Boone [12] described that the hearing impaired patient may demonstrate marked variations in nasal resonance (hyper- and hyponasality) which may be due to the inability to monitor the voice acoustically. Indeed, the 30 profoundly deaf children in the study of Fletcher et al. [10] had significantly higher nasalance values (i.e. the ratio of nasal to nasal-plus-oral acoustic energy (%), as measured with the Nasometer) compared with the normal hearing control group when nasal consonants were absent (reflecting hypernasality) and significantly lower when an utterance was loaded heavily with nasal consonants (reflecting hyponasality). Deviant nasal resonance in prelingually deaf children has been attributed to inefficient control of the velopharyngeal valve as a consequence of absent auditory feedback [7,10,11]. Other studies hypothesised that other commonly observed errors in deaf speech, such as a slow speaking rate, articulatory errors and the preference for the neutral vowel may give the impression of hypernasal resonance [6,7,9]. Besides this, Boone [12,13] stated that the excessive posterior posturing of the tongue in the hypopharynx lowers the second formant, resulting in a 'cul-de-sac resonance'.

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http://dx.doi.org/10.1016/j.ijporl.2015.01.025
0165-5876/

In the last decennia, cochlear implantation (CI) has become a standard procedure in the rehabilitation of prelingually deaf children. Even though these implants primarily facilitate speech perception, they are also an important aid in the development of several speech production skills, such as overall intelligibility [14–16], the production of vowels [2] and consonants [1]. The few studies which focused on resonance characteristics in children using CI [17–21] reported contradictory findings concerning several aspects of nasality or nasalance and conclusions were based on small sample sizes. Monini et al. [17] evaluated nasality in 3 children and 2 adults and concluded a reduction of increased nasality after the activation of the CI. Svirsky et al. [18] also reported an improvement in oral-nasal balance in 5 pediatric CI users a few minutes after the CI had been turned on, suggesting that those children used the auditory signal to improve their control of nasalisation. Van Lierde et al. [19] found a statistical difference between the nasalance scores for a nasal reading passage in 9 CI children and 6 HA children, measured by means of a Nasometer. The CI children had significantly lower nasalance percentages in comparison with the HA children and normative nasalance values [19]. This may reflect hyponasality. However, no differences were measured for the isolated/m/, oronasal reading passage and perceptual judgements. In the study of Lenden and Flipsen [20] resonance quality remained deviant in the 6 CI children. The majority of the inappropriate utterances were coded as ‘nasopharyngeal’, more specified as ‘cul-de-sac resonance’ (i.e. the muffled quality produced by air resonating in a blinded cavity caused by tight anterior constriction or by deep retraction of the tongue into the oral cavity and hypopharynx [22]). Finally, Nguyen et al. [21] also demonstrated a reduction of increased nasalance values following implantation in 6 prelingually deaf children.

Although some studies concluded normalisation of nasality and nasalance after implantation, deviant resonance characteristics, including hyponasality and cul-de-sac resonance, were reported as well. To the best of our knowledge, only the pilot study of Van Lierde et al. [19] has been found that used perceptual (nasality) as well as objective (nasalance) assessment techniques to compare resonance characteristics between CI children and children using conventional hearing aids (HA). Nonetheless, all conclusions of previous studies were based on small sample sizes. The aim of this study was to determine and compare the objective as well as perceptual resonance quality of a larger sample of CI children with values of age matched HA users as well as normal hearing (NH) children. Based on previous studies, significant differences between the resonance characteristics of the CI and HA children with the NH children were hypothesised. The authors also investigate a possible correlation between (1) the age of implantation (CI children) and nasalance, (2) between aided hearing thresholds and nasalance (for CI and HA children) and between unaided thresholds and nasalance (CI and HA children).

2. Methods

This study was approved by the human subject committee of the Universtity of Gent (reference number: 06017).

2.1. Subjects

Sixty-one prelingually hearing-impaired children, all enrolled in Flemish oral/aural rehabilitation programs before the age of 3 years, were selected to participate in this study. They all suffered from non-syndromal congenital hearing loss and each child had received a first hearing aid before the age of 3 years. A minimal performal intelligence quotient of 80 and the use of Dutch oral communication mode was required. Thirty-six prelingually deaf children (16 boys and 20 girls, mean age of 9;0 years, range 6;3–11;8 years) received a multichannel cochlear implant (CI) at the age of 3;4 years on average (range 6 months–10;9 years). Twenty-five children (15 boys and 10 girls, with a mean age of 9;1 years, range 6;8–11.10 years) were bilateral conventional hearing aid (HA) users with a moderate to profound hearing loss. All children had at least one year of experience with their current device (HA or CI), which was fitted by experienced audiologists. Eight CI children received a contralateral CI at a mean age of 4;10 years (range 2;6–6;3 years). The HA group consisted of 10 moderately hearing-impaired children with average better ear pure tone thresholds below 70 dBHL (HA $<$ 70 dBHL; PTA range 58 dB–68 dB) and 15 severely-to-profoundly hearing-impaired children with thresholds above 70 dBHL (HA $\geq$ 70 dBHL; PTA range: 72 dB–105 dB), 7 of whom were profoundly hearing impaired with thresholds above 90 dBHL (PTA range 90 dB–105 dB). The control group consisted of 26 normal hearing children (NH; 12 boys and 14 girls) with a mean age of 9;3 years (range 6;11–12;0 years). For the three subgroups, information concerning chronological age, and, where appropriate, age at first hearing aid fitting, most recent better ear unaided hearing threshold (PTA), most recent free field aided hearing threshold and age of implantation is provided in Table 1.

2.2. Procedures and materials

2.2.1. Objective assessment of nasal resonance

The Nasometer (model 6200; Kay Elemetrics 1994) microcomputer-based system developed by Fletcher and Bishop [23] was used for registration of the nasalance values. The position of the Nasometer headset was adjusted in accordance to the manufacturer's specifications. Each subject was then asked to sustain three vowels (/a/,/i/,/u/), and one consonant (/m/) and to read the Dutch reading passages designed by Van de Weijer and Slis [24]. These stimuli are comparable to the type of English passages that are designed specifically for use with the Nasometer. The first passage, an "oronasal" text, contains approximately the same percentage of nasal consonants, (11.67%, 29/251), found in standard Dutch speech (11.63%) [25]. The second passage, an "oral" text, excludes nasal consonants and can be used to detect hypernasality. The last passage, a "nasal" text, is loaded with nasal consonants (57%) and is designed to detect hyponasality in a subject's speech. Children who were not able to read (29,89%, 26/87), were asked to repeat the text sentence by sentence. In addition, all children were asked to repeat sentences from the SNAP test by MacKay and Kummer [26], which was translated and adapted to Flemish [27]. This test

Table 1
Characteristics of the CI, HA and NH groups.

	Chronological age (years)	Age at first HA (months)	Better ear hearing threshold unaided (dBHL)	Free field aided hearing threshold (dBHL)	Age at implantation (years)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
NH group (n = 26)	9;3 (1;9)	–	–	–	–
HA group (n = 25)	9;1 (1;7)	13 (10)	78 (16)	36 (7)	–
CI group (n = 36)	9;0 (1;9)	12 (9)	108 (12)	34 (8)	3;4 (2;11)

NH = normal hearing; CI = cochlear implant; HA = hearing aid; SD = standard deviation.