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Production of consonants by prelinguistically deaf children with cochlear implants

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Abstract
Consonant production following the sensory restoration of audition was investigated in 22 prelinguistically deaf French children who received cochlear implants. Spontaneous speech productions were recorded at 6, 12, and 18 months post-surgery and consonant inventories were derived from both glossable and non-glossable phones using two acquisition criteria. The results showed that children initiated appropriate production of consonants after six months of implant use. Stops and labials were the most frequently produced speech sounds, whereas glides and palatals were still infrequent after 18 months. Speech accuracy also improved throughout the study. Consonant visibility appeared to influence the order of acquisition in the first months following the implantation and, as experience with auditory information increased, patterns of development tended to resemble those seen in children with normal hearing. Finally, a signed mode of communication and oral rehabilitation programs prior to implantation were better outcome predictors than age at implantation.

Keywords: Speech development, hearing loss, sensory restoration, linguistic feature, mode of communication

Introduction
Auditory input plays an important role in the acquisition and production of linguistic units. Children who suffer from severe deafness cannot rely on this sensory contribution. Cochlear implants permit the stimulation of the remaining surviving cells of auditory pathways in some hearing-impaired (HI) children. A growing body of literature has shown that this sensory restoration can benefit the acquisition of several speech skills such as suprasegmental features (Tye-Murray, Spencer, & Woodworth, 1995), vowels (Ertmer, Kirk, Seghal, Riley, & Osberger, 1997), consonants (Grogan, Barker, Dettman, & Blamey, 1999), as well as intelligibility (Osberger, Maso, & Sam, 1993) and conversational abilities (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003). Given the strong relationship between
speech perception and speech production, one way to evaluate the effectiveness of the sensory restoration provided by the cochlear implant is to measure the quality of the implanted child’s spoken language. Tobey et al. (2003) found that correct consonant production was correlated with intelligibility and that it was strongly associated with average speech use and sentence duration.

Consonant development in normally hearing children

The emergence of consonants in the prelinguistic vocalization of normally-hearing (NH) infants has been studied extensively (Boysson-Bardies, Sagart, & Bacri, 1981; Robb, Bauer, & Tyler, 1994), as well as how these phonemes are gradually integrated into the productions of older children. Overall, results agree that there is no single universal order for the acquisition of speech sounds (Dinnsen, Chin, & Elbert, 1992). However, some developmental trends characterize both the phonetic and phonological development of this class of phonemes regardless of the target language. Thus, with respect to manner, stops, glides and nasals are the first to emerge, followed by fricatives and liquids. For place of articulation, consonants produced in the front of the oral cavity precede the posteriorly produced ones.

Consonant development in deaf children before and after cochlear implantation

Hearing-impaired children babble less (Maskarinec, Cairns, Butterfield, & Weamer, 1981), enter the stage of canonical babbling later than their NH peers (Oller, 1986) and produce fewer multisyllabic consonant-vowels strings (Kent, Osberger, Netsell, & Hustedde, 1987). In contrast to their NH peers, the consonantal inventories of HI children are smaller and remain stable or decrease with age (Stoel-Gammon & Otomo, 1986). Qualitatively, HI children produce more labials because of the visual cues associated with the production of this type of consonants (Smith, 1975; Stoel-Gammon, 1988). They also favour non-syllabic, prolongable consonants such as nasals, fricatives, glides, and liquids because of their tactile and kinaesthetic components (Stoel-Gammon, 1988). Thus in the absence of auditory cues, extra-auditory factors appear to influence the nature of the phonetic repertoire in HI children. Deafness also impacts consonant accuracy: fricatives and liquids are more affected than nasals, stops, and glides (Markides, 1970), posterior consonants are produced less accurately (Gold, 1970) and voicing errors are frequent (Smith, 1975).

The consonants produced by a child during the first 12 months following partial auditory restoration has been studied by Ertmer and Mellon (2001). These authors noted the influence of visual cues as reflected by the important proportion of labials early on, as well as the gradual emergence of less visible places of articulation. These observations suggest that the available acoustic information was progressively used by this child to monitor her speech and diversify her production. One of the most detailed reports in the segment inventories of implanted children is by Serry and Blamey (1999) and Blamey, Barry, and Jacq (2001) who examined the speech production of nine prelinguistically deaf children during their first 6 years post-implant. Using spontaneous speech samples, they used two criteria to account for the phonetic and the phonologic acquisition of vowels and consonants. Their results showed that the process of phone acquisition in these children was systematic, but slower than in NH children.

The quality of consonants produced by implanted children and children wearing tactile aids was found comparable at baseline, but differed greatly after 18 months of experience.
with their respective devices (Seghal, Kirk, Svirska, Ertmer, & Osberger, 1998). Whereas quality of production on the three consonant features improved with cochlear implants, there was no change with vibrotactile aids during the same period. The authors concluded that consonant features were more effectively transmitted by electrical stimulation of the auditory nerve than by tactile stimulation delivered on the skin. Tye-Murray et al. (1995) studied errors in consonant production made by HI children, implanted (31–170 months of age) and who had an average of 36 months of auditory experience. They showed that stops and nasals were accurately produced, as well as consonants with visible articulatory movement.

The majority of the above-mentioned studies have principally relied on perceptual judgement to examine changes in speech production following cochlear surgery. They also focused on a single post-implantation point in time, or selected a first assessment period close to the activation of the device and a second one years after experience with the prosthesis. Although useful for examining linguistic progress, such studies have not documented the gradual developmental changes. Another limitation is related to the type of speech samples obtained. A variety of speech tasks may be used in evaluating speech proficiency, including imitative tasks, standard articulation tests and spontaneous speaking. The first two types allow greater homogeneity and control over the collected data, but seldom reflect the child’s functional speech and everyday communication skills. In contrast, spontaneous speech is usually more representative of the child’s abilities as it does not depend upon imitation. Also, most studies to date have been case reports or included a very small number of children. Though they are highly informative, it is difficult to draw general conclusions from such studies with respect to the linguistic development of atypical populations. Finally, normal development represents a foundation for the investigation of speech acquisition in atypical populations. Yet, there is an absence of contrast with patterns of development considered typical.

Factors affecting speech production post-implantation

Age at implantation. The general conclusion is that an early age at time of implant surgery is associated with good language production and recognition outcome (e.g. Connor, Hieber, Arts, & Zwolan, 2000; Le Normand, 2005). Children who received their implant in infancy (before 19 months of age) show normal language acquisition and significantly better speech perception, speech intelligibility and spoken language than children implanted somewhat later, between 19 and 30 months (Hammes, Novak, Rotz, Willis, Edmondson, & Thomas, 2002). Earlier implantation apparently helps capitalize upon this enhanced auditory sensitivity.

Mode of communication. Systems of signing can integrate full language structures as in American Sign Language (ASL) and French Sign Language (FSL), or structures similar to spoken language as in Signed English (SE) or Signed French (SF). Another type of visual support is Cued Speech (CS) consisting of manual cues designed to facilitate speechreading by highlighting distinctive features of speech. Early use of manual communication may have a positive impact on early language, reading and vocabulary (Connor et al., 2000), but evidence shows that children enrolled in strictly oral programs show better speech perception, production and language development (Moog & Geers, 2003; Tobey et al., 2003).
Language and speech. The language and speech abilities of the children at the time of implantation is another important factor (Tye-Murray et al., 1995; Uziel, Mondain, & Reid, 1995). Although the literature is not yet conclusive (Nikolopoulos, Dyar, & Gibbin, 2004), results tend to suggest that children who present important speech delays at the time of the implantation would remain behind their counterparts with better expressive capacities at the time of the surgery (Miyamoto, Svirsky, & Robbins, 1997). Thus, despite improvement in speech performance, the progression speed of these delayed children wouldn’t permit them to compensate for their initial lags (Loundon, Busquet, Roger, Moatti, & Garabedian, 2000).

Objectives of the study

This study pursued three main objectives: to examine the phonetic and phonological development of consonants in spontaneous speech during the first 18 months following the cochlear surgery; to investigate how preoperative level of oral communication, age at implantation and mode of communication influence the acquisition of consonants; and to determine the extent to which the acquisition patterns of these implanted children correspond to those of their NH peers.

Method

Participants

The participants in this study were 22 prelingually deaf French children, 10 girls and 12 boys, who received a multichannel cochlear implant. The socio-demographic and clinical characteristics of the subjects are presented in Table I. They all had complete audiological, neurological, and linguistic evaluations prior to receiving the cochlear implant. The participants were followed at one of four French hospitals in Montpellier, Lyon, Toulouse or Paris. The only exclusion criterion was the presence of a handicap other than deafness. All participants lived in a home environment that principally used oral language, although communicative support—such as cued speech, SF, and FSL—was offered to some of them. Preoperative hearing loss in the better ear was expressed as pure-tone average threshold (PTA) at frequencies of 500, 1000 and 2000Hz in dB HL. All the children in the study were enrolled in auditory rehabilitation programs. Rehabilitation consisted of one-hour individual sessions, from the time hearing loss was diagnosed through the post-operative period. The frequency of the sessions varied from weekly to monthly visits as time progressed.

Cochlear implants. All participants except three children were implanted with the multichannel Nucleus CI24M, manufactured by Cochlear Corporation and using one of two speech strategies: the spectral peak (SPEAK) and the Continuous Interleaved Sampling (CIS). Children 13, 16, and 18 were implanted with the Clarion multichannel cochlear implant manufactured by Advanced Bionics Corporation and using the CIS strategy.

Procedure

Assessments were conducted at 6, 12, and 18 months post-implantation. Twenty-minute speech samples were video- and audio-taped by clinicians in a standardized free-play session. The set-up included Fisher-Price® toys, a toy house, figurines and household items. Children were asked to verbalize as many manipulations and actions as possible with toys and objects in and around the house. Speech skills (production and comprehension)
prior to implantation were assessed with a questionnaire completed by both parents and speech therapist, listing words and phonemes that were produced and perceived by the children in everyday situations. Word comprehension was scored on a 0- (none) to 5-point (consistent identification of words in sentences) scale and speech production was expressed on a 1- (none) to 5-point (few isolated words) scale.

Transcriptions. Broad transcription of speech utterances was adopted following Shriberg and Lof (1991). Three transcribers completed transcriptions from the audiovisual recordings. Both glossable and non-glossable utterances were transcribed. Crying, laughter, and vegetative sounds were not considered in the transcriptions. An utterance was defined as a vocalization or a group of vocalizations separated from all others by either audible ingressive breaths or a by utterance boundaries indicated by a silence of 1s or longer in duration (e.g. Lynch, Oller, & Steffens, 1989). Speech samples were transcribed using the symbols of the International Phonetic Association (IPA) notation system and formatted in accordance with the Codes for the Human Analysis of Transcripts (CHAT) transcription conventions of the CHILDES (MacWhinney, 2000). As children were not equally talkative the transcriptions were limited to the first 100 intelligible words of each sample.

Agreement of the phonetic transcriptions. Point-by-point comparisons of the transcriptions were conducted. The average inter-rater agreement was over 85% for the 66 speech samples transcribed (i.e. 22 participants × 3 sessions).
Phone classification. Transcribed consonants were divided into: glossable and non-glossable categories. Two measures derived for glossable segments (Tye-Murray & Kirk, 1993): total number of target sounds spoken (TSS) or number of times each sound was spoken in a word context; correct production (CP) or number of times a spoken sound matched the intended target. Another category, the total production (TP) referred to the number of times a spoken phone was produced, whether in a glossable or a non-glossable utterance.

Acquisition criteria. Two criteria, the emergent phone (EP) and the acquired phone (AP) (Serry & Blamey, 1999; Blamey et al., 2001), were used to define and identify two endpoints in the development of consonants. The EP criterion required that at least two tokens of a phone be found in the TP class; the AP criterion only counted phones in the glossable category, requiring at least two occurrences of a phone in the TSS class and at least 50% of these attempts to be a correct production. Group acquisition of a particular phone required that 11 out of the 22 participants had reached the EP or AP criterion.

Results
For the 6, 12, and 18-months assessments, t-tests on glossable-only and both glossable and non-glossable inventories yielded no significant differences on the total number of consonants produced between the two types of inventories. Therefore, only results from glossable and non-glossable inventories, or total production, will be reported in the results section.

Inventory
With respect to manner of articulation, stops were the predominant class of consonants, ranging between 55% (6-months assessment) and 45% (18-months assessment). The other classes of consonants followed with smaller rates, which varied between 10 and 15%. With respect to place of articulation, labials were the top ranking category at 6 months. Alveolars increased gradually over the three assessment periods. Finally, voiced consonants represented the most frequent class of phonemes at each assessment period.

Patterns of acquisition. As early as 6 months post-implantation [m, p] had already been acquired following both the emergent (EP) and the acquired (AP) criteria. Over the duration of the study, 10 other consonants reached the two criteria [l, b, n, w, t, j, d, s, r, s].

Speech errors. The consonant production of the 22 subjects were further assessed for accuracy of production. Confusion matrices showed that as early as 6 months post-implantation, speech production was relatively good with accuracy ranging between 64% for fricatives and 95% for stops. Stops remained the most accurately produced phonemes at all assessment periods and fricatives remained the less accurately produced. When substitution occurred, fricatives were usually replaced by a stop consonant.

Mode of communication, age at implantation and pre-implant level of oral communication. Pearson’s r correlations were conducted to determine the relationship between speech production and level of oral communication pre-implantation, age at implantation and mode of communication. Computations were performed on both glossable-only inventories and total production. With respect to the preoperative level of oral communication, significant correlations were obtained for the glossable inventories at 6...
months (r(20) = .58, p < .05), 12 months (r(20) = .56, p < .05), and 18 months (r(20) = .44, p < .05). For total production, there was a significant relationship at the 6-month assessment only (r(20) = .42, p < .05).

A positive relationship was found between age at implantation and total production at 6 months post-implantation (r(20) = .52, p < .05) only. Biserial correlations were computed on the two inventories to establish the relationship between mode of communication and vowel production. The oral system (oral and cued speech) was given a value of 1, whereas total communication approach (SF and/or SFL) was given a value of 0. When a child used both CS with any form of total communication, he or she received a score of 0. No correlation was found to be significant in the both glossable and non-glossable inventory. Significant correlations of interest were found in the glossable-only inventory, at the 6-month (r(20) = .49, p < .05) and 18-month assessments (r(20) = .46, p < .05) suggesting that children in oral communication produced more phonologically-aimed consonants.

Discussion

The present study investigated the phonetic and phonological development of consonants during the first 18 months post-surgery in prelinguistically deaf French children who received a cochlear implant. The results revealed three key findings. Stops and labials are the most frequently produced phonemes following partial restoration of auditory experience, whereas glides and palatals are still infrequent after 18 months of auditory experience. Second, speech accuracy is relatively good as early as 6 months and improves throughout the study. Finally, the pre-implant level of oral communication is more strongly related to consonant production than are clinical variables such as age at implantation and mode of communication.

With respect to speech production, results showed that consonant visibility appeared to influence the order of acquisition initially, but as experience with auditory information increased, patterns of development became more similar to those seen in NH children. However, the influence of auditory restoration on consonant development is complex. In children, psychological maturation and the plasticity of the sensory pathways take part in the natural evolution of communication. This makes it difficult to tease out the contribution of the acoustic information from maturation and rehabilitation effects. Also, these children still have limited hearing in one ear and their aided thresholds in the implanted ear remain in the mild to moderate range of hearing impairment. As such, they still receive less than optimal access to speech at conversational frequencies.

Despite this limited perception, the correspondence between acquisition patterns of these implanted children and NH children can be determined. The dominance of stop consonants is in marked contrast to several studies conducted with HI children for whom fricatives and glides were favoured and stops seldom produced (Stoel-Gammon, 1988). Pre-implantation factors such as early diagnosis of the hearing impairment and use of amplification devices may have helped some of these children to develop a phonetic repertoire similar to that of their NH peers (e.g. Kent et al., 1987; Ertmer & Mellon, 2001). Also, the children in this study produced more anterior consonants, reflecting a reliance on visible cues (Dodd, 1976). Also, labials that are highly visible had the highest the production rates. They were followed by alveolars, velar/uvulars, and palatals. This ordering models a continuum of consonant visibility and supports the results of other investigations (Grogan et al., 1999; Ertmer & Mellon, 2001).
Though useful, vision is still insufficient to convey all of the information necessary for the perception and production of the full consonant inventory (Kuhl & Meltzoff, 1984). The emergence of the less visible places of articulation, as well as the high frequency and motorically more complex fricatives, are suggestive of a more sustained reliance on the acoustic signal. The results of this study also suggest that the major period of consonant emergence occurs somewhere around 12 months post-implantation. Increased use of auditory cues and self-correction helps with the acquisition of more complex and less visible consonants as well as the integration of phones in phonologically adequate contexts.

Speech errors

Analysis of the speech errors revealed that overall accuracy in consonant production was relatively good. This is in agreement with Tye-Murray et al. (1995) but in contrast to results reported by Smith (1975) and McGarr (1987) with profoundly deaf children using conventional hearing aids. It appears that restoration of the auditory modality enhances phone contrasts and use of auditory feedback in refining the articulatory strategies of the implanted children.

Fricatives are known to represent particularly difficult phonetic and phonological targets for HI children (Kent, 1992). Normally developing French children also have a strong tendency to avoid or miss this class of phonemes (Boysson-Bardies et al., 1981). Also, the higher frequency regions of these phonemes constitute an added difficulty for HI children—who can hardly perceive them prior to receiving the cochlear implant.

Predicting factors

The analysis of the relationship between age at implantation, mode of communication and level of oral language pre-implant with consonant production underlines the importance of separately considering glossable and non-glossable segments. There were significant correlations when analyzing glossable inventories, but not when considering the total production. The results showed that age at implantation was not related to consonant production, although implantation at a later age is frequently considered as having deleterious effects on perceptual outcome following the sensory restoration (e.g. Manrique, Francisco, Huarte, & Molina, 2004; McConkey Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004).

Mode of communication, however, was found to influence the number of phones produced in the glossable inventories. This finding suggests that oral approaches were more beneficial than total communication for the production of speech in linguistically aimed utterances. In the present study, total communication children relied principally on signs to communicate. Tye-Murray et al. (1995) reported that children who used sign systems prior to receiving a cochlear implant, kept relying on them after for at least 2 years after surgery. Apparently, sign users must visually attend to both oral and manual gestures, whereas oral communication users can focus on oral articulation only (Bergeson & Pisoni, 2004).

A key finding of the present study was the influence of pre-implant level of oral communication on consonant production. A poor level of oral communication prior to the sensory restoration persists after the implantation and negatively influences consonant development. Recently, Loundon et al. (2000) concluded that the preoperative level of oral communication was the most important prognostic factor when considering post-implant speech production; no matter the linguistic or perceptual abilities assessed, this was always
a principal factor, regardless of age at implantation. Results from studies by Archbold et al. (2000) with more than 20 children, and Tait and Lutman (1994) with 20 infants, showed that children who demonstrated good auditory-vocal abilities before the auditory restoration were those with higher post-implantation language performance.

Taken together, these results suggest that consonant development following the cochlear implantation is not only a matter of demographic and clinical variables such as age at implantation, auditory input, or education. It appears that how well the children communicate prior to auditory restoration is an essential component. This is a novel observation in the implant literature which, until now, has principally been concerned with the role of demographic and clinical variables to explain post-surgery outcome. Thus, the need to extend the scope of research on post-surgery variability to factors other than clinical and socio-demographic, appears crucial in this context.

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