Introduction

Those of us with normal hearing receive two kinds of sensory information when we talk. We get auditory feedback from the sounds of our own voice and we simultaneously obtain somatosensory information that arises from the muscles and soft tissues of the vocal tract. Under normal circumstances, information from the auditory and somatosensory modalities are neurally linked in the sense that each speech movement results in changes to both kinds of sensory input. We can appreciate the importance of the somatosensory system when we listen to the speech of individuals who have lost their hearing as adults. These people often retain highly intelligible speech for years after hearing loss. This is due wholly to the preservation of somatosensory input.
The linkage between auditory and somatosensory information probably develops early and shapes the initial acquisition of speech sounds in infants. Children that are born deaf or lose their hearing early in life and then subsequently receive a cochlear implant (CI) enable us to study the development of the auditory / somatosensory linkage. By assessing the manner in which speech production in these children changes when their implants are turned off, we can obtain information about the progressive development of the somatosensory support for speech production. In parallel, we can assess the extent to which auditory feedback remains crucial for speech production with time after implantation.

**Specific Aims**

Our goal is to study children with early cochlear implants to assess how both auditory and somatosensory functions contribute to speech and speech development. The project has two specific aims.

**Specific Aim One:** Our first goal is to document the development of the sound space and also speech related somatosensory function in early cochlear implant users. Our studies will entail acoustical measurements of speech sounds with the implant turned on and turned off. When the implant is off, the regulation of speech movements falls entirely to the somatosensory system. This kind of information is presently unavailable and we believe it documents not only how acoustical patterns mature and develop both with age and with use of the implant, but equally important, this will tell us the extent to which the use of the implant helps train up the recipients' somatosensory system. In effect, early implantation may have benefits beyond the auditory system in that it may help in the development of early somatosensory "expectations" regarding speech movements.

**Specific Aim Two:** A second goal is to determine the contribution of somatosensory function to early speech learning by explicitly manipulating these inputs in early implant recipients that are tested with their implants turned off. In these studies, we will directly manipulate somatosensory input in a speech learning task. Using a variant of a technique we have used to study speech learning in deaf adults (Nasir and Ostry, 2008) we will track the development of the somatosensory contribution to speech control using experimental manipulations that alter somatosensory feedback. By examining the corrections to speech movements that occur in response to altered somatosensory input, we can evaluate the developing role of this modality in speech. Our plan is to track speech learning in children with implants using a motion capture system to measure orofacial movements over the course of learning.
Methods

Development of auditory and somatosensory information in early speech learning

We will assess changes in speech production by measuring the acoustical space of early implant recipients both with the implant turned on and turned off, in a manner similar to that reported by Perkell et al. (2001) (also see Tye Murray et al., 1996). Children of different ages will be trained to recite simple rhymes that will include the sounds that define the boundaries of the vowel triangle, /i/, /a/, and /u/ in the F1–F2 formants plane. We will investigate to which extent the vowel space shrinks when the implant is turned off and expands when the implant is turned on and the manner in which this changes with age at implant (i.e., the duration of auditory deprivation) and with number of months following implantation (i.e., the amount of auditory experience with the implant). By examining the pattern of acoustical change under these conditions we can track both auditory development and the capacity to use somatosensory information in the absence of auditory feedback. We expect that the role of somatosensory support for speech production will increase over time, as a reflection of plastic changes in the cortical representation of sounds affecting both auditory and somatosensory areas. In line with previous research (Thai-Van et al., 2007), we also expect that the main factor for observing those changes will be the time in sound.

An important methodological issue is how we will motivate our subjects to talk without receiving acoustic feedback. Depending on the age of the tested child, we will use spontaneous speech, learned rhymes, or ask questions.

Speech motor learning and somatosensory input

The goal here is to assess the influence of somatosensory information on speech production in early implant recipients and its development with age. This will be done by examining the pattern of compensation shown when speech movements are altered by manipulations such as slightly tilting the body which results in a different than usual load to the speech articulatory apparatus and requires a compensatory response for correct speech movement. The goal here is to determine whether the children will be able to restore "normal" speech movements when the implant is turned off, that is, strictly on the basis of altered somatosensory information. The manipulation will be done using either an orthopedic table or a simple medical chair with a tilting back. A similar investigation has been done in adults (Shiller et al., 1999, 2001). The underlying assumption here is that altering the body
orientation will elicit enough perturbation in the speech production due to variation in the orientation of the gravity force acting on the jaw and the tongue.

The jaw position and orientation will be tracked by a motion measurement device using small sensors attached to the children’s chin. The measurement devices we are presently considering are:

- Electromagnetic marker imaging systems
  - Aurora, from NDI
  - Fasttrack, from Polhemus
  - MiniBIRD from Ascension
- Passive marker optical imaging systems
  - Vicon
  - Polaris, from NDI

It will of course be necessary to assess the compatibility of each of these devices with the implant electronics. The passive marker system will be best in this respect. The electromagnetic systems have the advantage that it would enable us to record jaw and also tongue movements at least in older children.

**Age range of the subjects**

Subjects starting at 12 months of age will be tested in the studies described in Specific Aim One. This corresponds to the minimum age of implant recipients in our department. In very young infants, we will get more babbling than speech. We are aware that older children will be much more cooperative subjects, allowing a better vowel space assessment. Nevertheless the goal is to assess the development of the sound space (and corresponding somatosensory function) as a function of both age of implant and the period following implantation.

We will conduct a longitudinal follow-up in children implanted at Edouard Herriot University Hospital (Lyon, France), although the time span will be limited to the duration of the Ph.D. thesis (3 years). To get sufficient cohorts, cross-sectional analyses will be emphasized.

For work related to Specific Aim Two, our hope is to recruit as young a cohort as is feasible. However we anticipate that age 3 to 4 is likely to be a lower limit.
Factors of interest

- Implant on or off
- Onset of deafness (congenital/prelingual, postlingual)
- Age at the time of implant
- Duration of deafness
- Duration of implant use

References


