Cortical Activity at Rest Predicts Cochlear Implantation Outcome

The functional status of central neural pathways, in particular their susceptibility to plasticity and functional reorganization, may influence speech performance of deaf cochlear implant users. In this paper, we sought to determine how brain metabolic activity measured before implantation relates to cochlear implantation outcome, that is, speech perception. In 22 prelingually deaf children between 1 and 11 years, we correlated preoperative glucose metabolism as measured by F-18 fluorodeoxyglucose positron emission tomography with individual speech perception performance assessed 3 years after implantation, while factoring out the confounding effect of age at implantation. Whereas age at implantation was positively correlated with increased activity in the right superior temporal gyrus, speech scores were selectively associated with enhanced metabolic activity in the left prefrontal cortex and decreased metabolic activity in right Heschl's gyrus and in the posterior superior temporal sulcus. These results reinforce the notion that implantation should be performed as early as possible to prevent cross-modal takeover of auditory regions and suggest that rehabilitation strategies may be more efficient if they capitalize on general cognitive functions instead of only targeting specialized circuits dedicated to auditory and audiovisual pattern recognition.

Keywords: cochlear implants, deafness, positron emission tomography, speech perception

Introduction

Cochlear implantation (CI) has attracted the attention of neuroscientists because it is the only available medical technique that can successfully replace a sensory organ in humans. CI provides a unique opportunity to study cortical plasticity associated with long-term deafness and restoration of the auditory modality. In patients who are born deaf (prelingually deaf), the intact senses, vision in particular, functionally “takeover” the superior temporal cortex through a process of cross-modal reorganization despite the fact that these regions receive inputs predominantly from auditory pathways (Levanen and others 1998; Petitto and others 2000). After critical maturation and language development steps, cross-modal pathways stabilize, and the auditory association areas in superior temporal regions can no longer be recruited by auditory stimulation, even though primary regions usually respond to electrical stimulation of the auditory nerve (Nishimura and others 1999). Accordingly, auditory language develops almost normally if implantation takes place early enough in life, that is, before language is acquired through vision and temporal language areas get cross-modally reorganized. The critical period for implanting congenitally deaf children thus revolves around the age of 2 years. If implantation is performed before this critical age, spoken language can develop with a dynamics comparable with that in normal-hearing children (Waltzman and Cohen 1998; Hammes and others 2002). Even more remarkable results can be obtained if implantation is performed before the age of one, which indicates that early exposure to speech sounds also contributes to the outcome (Schauwers and others 2004).

If the brain network normally dedicated to auditory language processing reorganizes during deafness and adopts a nonreversible functional specialization, as it seems to be the case in untreated prelingual deafness, auditory function after implantation will be constrained by the functional properties of the subset of regions that were spared from reorganization and remain available for auditory processing. If spared regions are limited to primary auditory regions, speech perception will be compromised because essential speech processing steps will be missing. Conversely, the larger the region that remains dedicated to hearing the better the chances of speech development. Therefore, the amount and location of deafness-induced plasticity should qualitatively and quantitatively predict the success of auditory language learning.

Although numerous studies report that duration of deafness accounts for most of the variance in the CI outcome in congenital deaf patients (O'Donoghue and others 2000; Sarant and others 2001), some cases demonstrate that other factors come into play. For instance, older prelingually deaf children sometimes succeed very well in understanding speech (Schramm and others 2002). So far, no consistent factor has been identified to account for such exceptionally good performance in late implantees, although demographic variables or peripheral factors as the number of remaining spiral ganglion cells in cochlea (Nadol and others 2001) seem to play a minor role. Yet, as cortical plasticity varies dramatically from one individual to the other, the individual status of cortical reorganization might efficiently predict individual CI speech outcome (Lee and others 2001).

Before implantation, deafness-induced plasticity can be detected as a hypometabolism in temporal lobes, and its extent and amount reveal whether those regions that are critical for speech perception remain available for auditory language (Lee and others 2001). If temporal areas appear nonhypometabolic before implantation, it indicates that they are involved in alternative brain circuits and cognitive networks and are no longer susceptible to auditory stimulation. The assessment of hypometabolism in superior temporal regions therefore seems to be a good method to make individual predictions about CI outcome. However, the amount of temporal hypometabolism mostly reflects age-related changes, that is, time-dependent brain plasticity (Lee and others 2001) and does not permit to effectively account for age-independent performance with an implant, for example, exceptionally good performance in some
older children. In a recent analysis of fluorodeoxyglucose positron emission tomography (FDG-PET) images (Lee and others 2005), we investigated the relationship between preoperative resting brain metabolism and CI outcome within a limited developmental age range (5–7.5 years) to minimize the effect of age-related plasticity while taking advantage of this developmental age where the broadest range of outcome can be observed (Oh and others 2003). Those deaf children displaying higher frontoparietal and lower ventral tempo-occipital metabolic activity were those with the best speech comprehension scores at 2 years after implantation surgery, whereas the reverse pattern was associated with a poor outcome. In the present article, we report results from a sample of 33 children aged between 1 and 11 years, in whom we probe a correlation between brain metabolism before implantation and speech comprehension measured 3 years after implantation after having 1) separately analyzed the effect of age at implantation (on the initial sample of 33 children) and 2) factored out the effect of age (on a sample of 22 children who could be followed-up). We thus expect to identify neurophysiological factors that might determine implantation outcome independently from age-related brain plasticity, while analyzing independently the effect of age at implantation on deaf children’s neurometabolic profile.

Patients and Methods

Patients

Thirty-three congenital deaf children (15 boys and 18 girls) aged 1.5–11.3 years (mean ± standard deviation [SD]: 6.3 ± 2.3 years) were recruited in this study from an available cohort of 61 congenital deaf children who underwent CI surgery in Seoul National University Hospital (from December 1996 to July 2001). Those 28 who were excluded presented at least one of the following conditions: inner ear malformation (n = 8), mental retardation, psychological problems (e.g., autism), cerebral anatomical abnormality (periventricular leukomalacia, large arachnoid cyst), and perinatal illness (intrauterine infection, severe neonatal jaundice) or history of education with sign language after CI. Autism, cerebral anatomical abnormality, and perinatal illness (intrauterine infection, severe neonatal jaundice) or history of education with sign language were the exclusion criteria. In the waiting room was far below 70 dB SPL, which corresponds to the lowest threshold of aided hearing in subjects with best residual hearing. We therefore confidently interpret the metabolic activity as spontaneous brain behavior in complete silence.

A transmission scan was performed using a Ga-68 rod source to establish attenuation maps immediately before an emission scan. During the emission scan, 47 slices of brain emission images were acquired over a 20-min period during which children received minimal sensory input (dimmed light and silence). Emission images were reconstructed in a 128 × 128 × 47 matrix with a pixel size of 2.1 × 2.1 × 3.4 mm using a filtered back projection method with a Shepp filter with a cutoff value of 0.35 cycles/pixel. All reconstructed images were corrected for attenuation, and the transaxial images were realigned to get sagittal and coronal images.

Speech Perception Scores

As speech perception capacity of young children develops for many years, we performed speech perception tests 3 years (at 29.6–45.7 months, mean ± SD: 36.2 ± 5.4) after CI. Only 22 out of 33 children who were scanned could be followed-up. The speech perception ability was measured by a sentence test (Korean version of Central Institute for the Deaf sentence test) for children with auditory cue only. Each list of sentences was composed of 20 sentences using words for children of 3 or 4 years equivalent age. Sentences were spoken by a speech therapist with her mouth hidden, and the correctly identified words in the sentences were scored. Speech perception scores after 3 years of rehabilitation showed a significant negative correlation with duration of deafness (Fig. 1, r = 0.597, P = 0.0027). Despite the significant negative correlation, in particular, among deaf children older than 5 years at implantation, sentence scores remained largely unpredictable on the basis of age at implantation alone.

Imaging Analysis

Image preprocessing (realignment, spatial normalization, spatial smoothing with a 16-mm full-width at half-maximum Gaussian kernel) and statistical analysis were carried out using SPM99 (Institute of Brain Metabolism and CI Outcome)
Neurology, University College of London, UK) implemented in Matlab 6.1 (Mathworks Inc., Natick, MA). In correlation analyses, global normalization of FDG uptake was applied so that the mean count of FDG uptake of PET images from each child’s brain was arbitrarily set at 50. This procedure was critical given the wide age range considered in this study. Correlation analyses were performed in a voxelwise manner between the preprocessed PET images and 1) age at implantation (\(n = 33, P < 0.005, \text{Fig. 2 and Table 1}\)) and 2) speech perception scores (\(n = 22, P < 0.005, \text{Fig. 3 and Table 2}\)), although age at implantation was treated in the latter statistical analysis as a confounding effect. This procedure is an essential step in our approach that seeks to identify factors that were independent from age at implantation. It additionally removes further confounding effects due to neuroanatomical and neurofunctional development normally occurring within the age range we considered.

Results are displayed on a brain surface and on high-resolution T1-weighted magnetic resonance reference images. In both correlation analyses, statistical threshold was set at \(P < 0.005\), as it was the strictest threshold that allowed to detect hypometabolic effects in temporal areas that were previously described by Lee and others (2001). We discuss later in Discussion why the present study is by nature less sensitive than previous studies (Lee and others 2001) in detecting similar effects.

Results

Age-Related Effects

Regions showing significant age-associated increase or decrease in FDG uptake are displayed in Table 1 and Figure 2. FDG uptake in orbitofrontal, superior frontal gyri, inferior parietal regions, cingulate cortex, right “superior temporal gyrus” (STG), and mesiodorsal thalamus increased with age (Fig. 2A). Age-related decrease in FDG uptake was mostly observed in periventricular white matter regions, an artifact that reflected an increase in brain size with age. Very sparse clusters of age-dependent decrease of activity were found in the gray matter (Fig. 2B).

Regions Predicting Postoperative Speech Perception by Preoperative FDG Uptake

The brain regions showing a significant correlation between FDG-uptake and speech perception scores are listed in Table 2 and displayed in Figure 3. Positive correlation indicates the brain regions showing a relative increase in FDG uptake for good perception scores, whereas negative correlation indicates those showing a relative increase in FDG uptake in worse performers. As age at implantation was treated as a confound in this analysis, the results are independent from those probed by the correlation with age described above.

Good speech perception was associated with a relative increase in FDG uptake in the posterior portion of the left dorsolateral prefrontal cortex (DLPF, Fig. 3, shown in red). The degree of FDG uptake in 3 speech-related regions as a function of age at implantation was plotted in Figure 4, which confirmed that the fluctuation of metabolic activity in these regions was strictly independent from age.

Poor speech perception was associated with a higher glucose activity in the right posterior superior temporal sulcus (STS) and in right Heschl’s gyrus (HG) (Fig. 3, shown in blue). The precise location within HG was checked using a probabilistic cytoarchitectonic map (Eickhoff and others 2005). The peak voxel (42 -20 12) coincided with the superomedial margin of the cytoarchitectonically defined primary auditory cortex (PAC), with 20% probability with respect to both TE1.0 and TE1.1.
These results confirm the dorsoventral dichotomy previously observed in a more restricted age range when comparing separate groups of good performers and bad performers (Lee and others 2005). In other words, patients with relatively high glucose activity in dorsal brain regions and relatively low activity in ventral brain regions tend to become successful CI users, whereas those with the reverse pattern tend to become poor implant users. This dorsoventral distinction is clearer when visualized using a lower statistical threshold on a surface rendering ($P < 0.05$) as in Figure 5.

**Discussion**

**Cross-Modal Plasticity in Auditory Areas: Age-Related Changes**

Auditory deprivation engenders global functional effects that can be assessed by quantification of cortical metabolism in relation with age (Kang and others 2004). The correlation analysis with age at implantation (Table 1 and Fig. 2) indicates brain regions susceptible to deafness-induced plasticity as well as to developmental changes. In this report, we focus on an effect of age at implantation observed in STG, which coincides with effects previously described in both prelingually and postlingually deaf patients (see below). Using 2-deoxyglucose, it has been shown that auditory cortices in neonatally deafened rats turn hypometabolic with a peak at 4 weeks and recover when the rats grow older (Ahn and others 2004). This effect most probably results from reorganization and a cross-modal takeover process. Likewise, hypometabolism has been detected in the temporal cortex of young congenitally deaf children, in comparison with normal-hearing controls. Its extent decreases with duration of deafness both in prelingually (Lee and others 2001) and postlingually deaf subjects (Lee and others 2003), which we currently confirm in a larger cohort. As we also confirmed here, the degree of temporal hypometabolism correlates positively with the implantation outcome (speech recognition), making temporal hypometabolism an interesting prognosis factor for CI (Lee and others 2001). Reduced metabolism in temporal cortices of deaf subjects indicates a latent susceptibility to auditory restoration. In analogy with animal studies, Lee and others (2001) proposed that an absence of relative hypometabolism reflects the recovery from a deprivation-induced hypometabolic state due to the takeover of temporal regions by alternative cognitive processes and would thus predict less susceptibility to auditory restoration and poor speech recognition outcome. This hypothesis is backed up by several lines of evidence showing that, when deprived from auditory input, auditory cortices become naturally implicated in alternative neural networks. Classically, reorganized auditory cortices may be activated by visual stimulation (Finney and others 2001) and sign language (Nishimura and others 1999; Petitto and others 2000) or even vibrotactile stimulation (Levanen and others 1998).

Plastic changes in auditory cortices are evidently strongly determined by the duration of auditory deprivation. Electrophysiological studies indicate delayed maturation of auditory pathways in deaf children (Ponton and others 1996), which manifests as the delayed cortical P1 response generated by auditory thalamic and cortical sources. Both the cross-modal takeover of temporal areas (Lee and others 2001) and the delay in P1 responses (Ponton and others 1996) correlate with deafness duration. Although P1 responses normalize within months in children who are implanted at a very young age, they only incompletely recover if implantation is performed after the age of 7 years (Sharma and others 2005). In our sample, deaf children who were older than 8 years showed a higher level of recovery from hypometabolism and a lower variability than younger children, suggesting that deleterious reorganization in auditory pathways occurred in most congenital deaf children after this age (Fig. 2A, plot). The failure of implantation in prelingually deaf adults probably results from an irreversible alteration of auditory functional properties after the age of 7–8 years (Kral and others 2002; Sharma and others 2002).

In the present study, we confirm a positive correlation between resting metabolism and age/duration of deafness in the right STG (Fig. 2A). The effect appears statistically less important in our study than in Lee and others (2001) because it was probed from a correlation analysis among deaf people rather than from direct comparison between deaf and normal-hearing controls. The latter reveals relative effects in the deaf compared with controls, and the variance in such analysis by far exceeds the variance in metabolism among the deaf. In a similar FDG-uptake study, Kang and others (2004) performed correlation with age/deafness duration in 87 children aged 1–15 years, but did not report metabolic effects in temporal areas. With their permission, we reanalyzed their data and found that an effect was present in bilateral STG at a lower statistical threshold than the one used in their previous report (Kang and others, 2004).
Figure 3. (A) Brain region showing correlation between $^{18}$F-FDG-uptake and speech perception scores ($N = 22$), when the effect of age has been factored out ($P < 0.005$). Regions showing positive correlation with speech perception are marked in red and negative correlation in blue. Regression plots between FDG-uptake and speech perception scores of the children are displayed in the corresponding sampled regions. (B) A coronal section ($y = -21$) showing the respective locations of regions of 1) age-related increase of metabolism (orange) and 2) speech-related negative correlation (blue) in right temporal cortex.
We therefore used here a statistical threshold of $P < 0.005$, which is acceptable for probing an effect that had been observed in previous FDG-PET investigations (Desgranges and others 2002; Lee and others 2003). We thus applied conventional statistical criteria for regions of interest analyses and set the statistical threshold as the strictest possible that permitted to observe age-related variations of metabolism in temporal cortices. This threshold was applied to both correlation analyses (with age and with speech-performance thresholds in both correlation analyses was essential to distinguish the relative importance and potential respective contribution of cross-modal reorganization and factors that are independent from age at implantation in the CI outcome.

### Speech-Related Metabolic Effects in Temporal Cortex

A negative correlation between FDG-uptake and speech perception scores after CI was found in the medial part of HG outside the PAC and in the depth of the right STS. An age-dependent effect was observed at the same anteroposterior level (see respective locations on Fig. 3B). The distribution of relative FDG uptake in the regions revealed by this correlation analysis was strictly independent from age (age factored out), and therefore the resulting effects do not point to cores of cortical plasticity related to deafness duration but reveal intrinsic metabolic trends already present as early as the age of our youngest subjects (1 year). The occurrence of age-independent and age-dependent metabolic effects in neighboring temporal regions is a peculiar finding, which might indicate that the region underwent very early embryonic plasticity that is already stable at the age of 1 and does no longer evolve between 1 and 11 years. The presence of 2 foci of age-independent-performance-related effect in HG and the STS could indicate that there were primarily 2 centers of embryonic cortical plasticity in early auditory cortex and auditory association area, which have stabilized before intermediate regions get further reorganized (age-related effects were observed in the STG between the 2 foci in HG and STS). However, this interpretation would only apply to congenitally deaf babies who became deaf at an early embryonic stage.

Alternatively, these effects might correspond to strictly time-independent trends of right temporal regions (negatively correlated with postimplant performance) to be spontaneously involved in cognitive networks that do not participate in speech perception. The involvement in alternative cognitive processes could even compromise the possibility of later speech perception. This early lack of auditory specification in temporal areas could be equivalent to an early synesthetic state occasionally suspected to characterize newborn sensory perception (Maurer 1997). This state could normally be bound to regress under auditory influence in normal-hearing subjects so that temporal cortex ultimately gets auditorily tagged. In deaf babies on the contrary, this synesthetic tendency would be sustained and would finally lead to the irreversible situation where these regions are no longer susceptible to hearing. Other PET findings further support the hypothesis that an early synesthetic state may interact with deafness (Kang and others 2003). They showed that metabolic activity in the PAC of young deaf children (but not of older deaf children, postlingually deaf adults, and normal-hearing adults) correlates with activity in a wide cortical network encompassing sensory motor areas.

Irrespective of their precise physiological origin that obviously remains speculative, these findings have important implications for the implantation practice. On the one hand, they suggest that it is crucial to implant as early as possible in life, and before the age of one, either to limit the possibility of very early reorganization or to promote an early recovery from a form of “synesthetic” state (auditory under specification) that might later lock the auditory system into a cross-modally organized fashion. On the other hand, detecting the involvement of temporal regions in other cognitive networks in older children should be taken as a sign that they may later be unsuccessful with their implant.

The strongest negative correlation with CI outcome was located in the depth of the right STS. Functionally, this area contributes to auditory complex pattern recognition (Maeder and others 2001) including voices (Belin and others 2000; Belin and Zatorre 2003; von Kriegstein and Giraud 2004). It is of course extremely difficult and risky to infer functional processes from resting metabolic findings, especially in subjects where reorganization is supposed to have taken place. Yet, we assume that this region is primarily auditory and therefore that higher metabolism during deafness should be interpreted as a change in functional specialization, that is, that regions normally underlying temporal pattern recognition get involved in other cognitive operations. If this region was primarily multimodal (Wright and others 2003; Beauchamp 2005), our interpretation would be the same as the one we propose below for extra-auditory areas.
**Effects in Temporal Extra-Auditory Areas**

The distinction between auditory and extra-auditory areas is crucial in the interpretation of our results. Indeed, deprivation-induced hypometabolism can be expected only in regions that are determined to receive auditory inputs at the endpoint of embryonic development. In regions that are multimodal by nature, higher metabolism in poor performers should not reflect the correction from a hypometabolic/deprived state but rather a trend to implicate this region during spontaneous brain activity. Unlike activation signals measured with functional magnetic resonance imaging or $H^{15}O$-PET, FDG uptake represents global synaptic activity integrated over an hour of rest (Rocher and others 2003) and unveils long-term brain-behavior relations (Kang and others 2004), default behavior or traits (Seidenwurm and others 1997; Youn and others 2002), and cognitive ability (Boivin and others 1992; Newberg and others 2003). Recent animal studies confirmed remarkably reliable relationships between behavior and neural metabolism at rest (Sakata and others 2005). The effects observed in spontaneous cognitive behavior hence denote default cognitive networks that may be good predictors of the cognitive network and strategies individually used by the subjects when submitted to more explicit cognitive demands.

Poor outcomes were associated with higher metabolic activity in large ventral regions including fusiform regions and lower occipital regions (Fig. 5). This is concordant with earlier observations on a more restricted sample of subjects, showing higher resting hypermetabolism in more ventral temporal regions, that is, bilateral fusiform gyri, when comparing children CI users with poor speech perception with those with good speech perception (Lee and others 2005). The relative increase in ventral temporal activity can be assumed to reflect a trend in deaf children who will later become poor performers to recruit posterior and ventral regions during natural thinking and therefore also possibly when they will come to perform more explicit cognitive operations (Sakata and others 2005). Functionally, posterior-ventral regions are recruited during visual, auditory, and even tactile complex pattern recognition. Activation of these regions usually relies on a high expertise and familiarity with the stimuli encountered (Gauthier and others 2000; Amedi and others 2001; Kourtzi and Kanwisher 2001; von Kriegstein and others 2005). Increased metabolic activity in posterior-ventral regions in poor performers might be predictive of the implication of these regions in such tasks as speech recognition with an implant, in which stable pattern recognition might be a very bad strategy given that the signal is degraded and highly fluctuant in time.

**Effects in Extratemporal Areas**

The only regions showing a significant positive correlation with speech recognition performance were observed in the left DLPF. Following the same reasoning as before, children who had a higher metabolism in this region during spontaneous brain activity were those who became good CI performers. Functionally, the left DLPF participates in higher cognitive functions such as reasoning, attentional control, or working memory (Milham and others 2003; Badre and Wagner 2004; Goel and Dolan 2004; Volle and others 2005). The effect in the left DLPF overlapped with an activation focus ($H^{15}O$-PET) that was previously observed during attentive rest in very good CI adult performers (−40 8 40) (Giraud and others 2000). As this effect was not observed in normal-hearing controls doing the same task, we assume that listening to degraded implant speech signals requires an increased engagement of DLPF and that subjects who recruit this region during spontaneous brain activity...
activity will subsequently have an advantage in acquisition of auditory language.

As we did for the negative effects, we looked at positive correlations with a low statistical threshold and disclosed a broader network that encompassed a large portion of both frontal and superior parietal cortices (Fig. 5). This frontoparietal regions dominated in left prefrontal cortex including Broca’s area. Typically, dorsal cortices are related to general cognitive competences as attention, working memory, and general intelligence. By the increased loading on general intelligence, cognitive tasks with very different surface content share frontonal cortical network including the left inferior prefrontal region reported here (Duncan and others 2000).

The left prefrontal region also participates in phonological and semantic processing irrespective of the modality of input (Poldrack and others 1999; Booth and others 2002; Marinkovic and others 2003). Even in children with a long-standing deprivation who probably acquired some linguistic skills through vision, recruitment of this region at rest predicts a good performance with the auditory modality although it never served for spoken language. Our findings seem to indicate that dorsofrontal areas are less susceptible to reorganization than temporal association areas and that their contribution to cognitive processing depends minimally on sensory experience. This fits with recent findings indicating that the role of Broca’s area in language processing more generally relates to the processing of hierarchically organized temporal sequences than to specific categories of sensory stimuli (Koechlin and Jubault 2006).

In our previous report (Lee and others 2005) involving children in limited age (5–7.5 years), we showed an even wider frontoparietal network than here. In the 2 studies, regions positively related with good speech-performance overlap in a large frontoparietal network that is the one usually implicated in attentional control or working memory (Wojciulik and Kanwisher 1999; Honey and others 2002; Bledowski and others 2004). This dorsoventral distinction can be related to observations in rats showing that those individuals presenting low prefrontal metabolism tends to display attention deficit disorders and specific behaviors that characterize some aspects of depression (Sakata and others 2005). The tendency of deaf subjects to engage left prefrontal and more generally frontoparietal networks during spontaneous brain activity might suggest that after implantation they will spontaneously engage the same regions during task with more explicit cognitive demands as speech processing. As these regions are crucial for language processing and particularly implicated when processing implant speech, this tendency should contribute to better performances.

Conclusions

Overall, these findings point to 2 main determinants of CI outcome. The first one lies in the reorganization that has taken place in auditory cortices, which can be seen as a limiting factor: if immediate auditory association areas have been taken over by vision or other cognitive processes, subsequent implantation is likely to engender a poor outcome. Our results further indicate that the auditory specification of temporal regions may be weak in some very young children and that it is therefore important to identify them and equip them with an implant as early as possible. The other determinant lies in general patterns of brain activity. In profoundly deaf people, a higher tendency to implicate frontoparietal networks, and in particular left prefrontal area, during spontaneous brain activity predicts a good CI outcome, whereas a higher tendency to engage posterior-ventral cortices, in particular right-sided temporal regions, predicts a poor outcome. We currently do not know how flexible, or on the contrary how robust, these tendencies are in humans, but it might still be useful to try to rehabilitate implanted children using specific training that promotes general supramodal cognitive strategies over audiovisual pattern recognition.

In summary, a deaf child is expected to have the best CI result if, while keeping his/her auditory cortex deprived, he/she relies more on general cognitive strategies implicating the prefrontal cortex (reasoning, working memory) rather than ventral temporal circuits (pattern recognition, long-term memory). These conclusions will need to be precisely tested in further functional experiments. In particular, it will be interesting to relate speech performance to general cognitive abilities measured in young deaf children before the implantation surgery. If we can delineate exact functional/behavioral meaning of this dorsoventral distinction of resting metabolism, we may have stronger predictive tool for CI outcome and an opportunity to develop effective rehabilitation program and even preimplantation training.

Notes

This study was supported by grant No. R01-2002-000-00346-0 from the Basic Research Program of the Korea Science & Engineering Foundation. HJL was granted by Brain Korea-21 program. Authors thank Andreas Kleinschmidt for his kind commentaries. Conflict of Interest: None declared.

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