Hearing Research 343 (2017) 128–137

Contents lists available at ScienceDirect

Hearing Research

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

Review Article

Cortical reorganization in postlingually deaf cochlear implant users: Intra-modal and cross-modal considerations

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ARTICLE INFO

Article history:
Received 15 April 2016
Received in revised form
12 July 2016
Accepted 18 July 2016
Available online 26 July 2016

Keywords:
Cochlear implant (CI)
Postlingual deafness
Cross-modal reorganization
Intra-modal reorganization
Brain plasticity
Auditory deprivation

ABSTRACT

With the advances of cochlear implant (CI) technology, many deaf individuals can partially regain their hearing ability. However, there is a large variation in the level of recovery. Cortical changes induced by hearing deprivation and restoration with CIs have been thought to contribute to this variation. The current review aims to identify these cortical changes in postlingually deaf CI users and discusses their maladaptive or adaptive relationship to the CI outcome. Overall, intra-modal and cross-modal reorganization patterns have been identified in postlingually deaf CI users in visual and in auditory cortex. Even though cross-modal activation in auditory cortex is considered as maladaptive for speech recovery in CI users, a similar activation relates positively to lip reading skills. Furthermore, cross-modal activation of the visual cortex seems to be adaptive for speech recognition. Currently available evidence points to an involvement of further brain areas and suggests that a focus on the reversal of visual take-over of the auditory cortex may be too limited. Future investigations should consider expanded cortical as well as multi-sensory processing and capture different hierarchical processing steps. Furthermore, prospective longitudinal designs are needed to track the dynamics of cortical plasticity that takes place before and after implantation.

Contents

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http://dx.doi.org/10.1016/j.heares.2016.07.005
0378-5955/

1. Introduction

In 2008, one of us (S.D.) reported on a 71-year-old male cochlear implant (CI) user, who had been using a CI for 4 years before he entered our laboratory (Debener et al., 2008). This gentleman could easily communicate without the help of visual cues. He had suffered from a gradually deteriorating sensori-neural hearing loss since the age of four and reported being severely hearing impaired for half of his life, with no satisfactory benefits from hearing aid use. By the age of 67, after decades of silence, he received a CI, and speech perception returned within a few months. Remarkably, in the electroencephalogram (EEG) laboratory, we found near normal, age-appropriate late cortical auditory evoked potentials (AEPs). This case is of course anecdotal and should be treated with care, but it is a reminder that humans retain clear capacity for brain plasticity, even during later years and even after decades of sensory deprivation.

In sensory and motor systems, lack of experience (or lack of use) results in shrinkage of the cortical representations of non-used systems or limbs (Polley et al., 2006; Steven and Blakemore, 2004). This shrinkage process is typically paralleled by a redistribution or invasion of abandoned regions by remaining sensory modalities, representation zones or effectors (e.g., Milliken et al., 2013). Here the more relevant findings than reports of use-dependent plastic changes are studies on the potential interaction between deprivation-induced and restoration-induced changes. A seminal study exploring this interaction in the motor system showed that individuals cannot be expected to easily regain their original pre-deprivation movement and corresponding cortical representations after experiencing a shrinkage of cortical representation induced by movement restriction (Milliken et al., 2013). A similar variability of recovery is observed in adult CI users. Despite CIs being by far the most successful neuro-prosthesis available (Wilson and Dorman, 2008), some CI users recover poorly, and changes in cortical representation have been found to contribute to this variation.

Several previous reviews on deprivation-induced cortical reorganization highlighted for instance the mechanisms of underlying maturation during early development and prelingual deafness (Kral and Eggermont, 2007; Kral, 2007; Kral et al., 2016; Merabet and Pascual-Leone, 2010; Sharma and Glick, 2016). Others have explored similarities between the cortical changes of early deaf and blind individuals (Heimler et al., 2014; Merabet and Pascual-Leone, 2010). However, given our aging society and the prevalence of age-related hearing loss that often develops during adulthood, postlingually deaf individuals are nowadays the principal population for CI therapy. Mechanisms and patterns of cortical reorganization may differ between pre- and postlingually deaf CI users, because the auditory system is assumed to be normally developed before the onset of deafness in postlingually deaf, but not in prelingually deaf individuals (Heimler et al., 2014; Kral, 2007; Petersen et al., 2013). Thus in the present review, we focus on cortical differences in adult, postlingually deaf CI users.

Fig. 1 is a schematic illustration of possible patterns of reorganization due to auditory deprivation (B-D) and hearing restoration with a CI (E-G). The figure will be used throughout the review to illustrate configurations of changes and possible pathways of reorganization. All illustrated differences in cortical configurations are shown in comparison to the normally matured auditory system (A). Different stages of sensory deprivation such as moderate hearing loss or profound deafness might induce various patterns of cortical changes. The take-over of the auditory cortex by other modalities, as presented here the visual system, can be weaker or more pronounced (B, C). Cross-and intra-modal changes could as well emerge within and between both the visual and the auditory modality (D). It is not well understood how these changes contribute to changes following sensory restoration with a CI. So far, the common view mainly interprets the particular configuration of reorganization known as visual take-over, as reflecting residual, deafness-induced changes that have not been fully reversed by CI use (Fig. 1 A versus E). However, extended CI use may not necessarily result in either a restored pre-deprivation organization

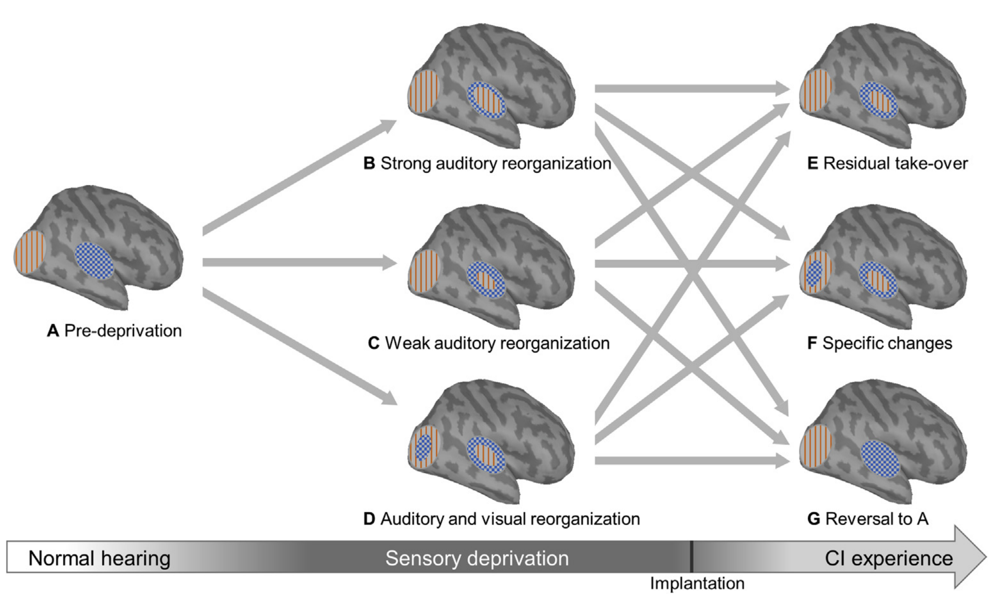

Fig. 1. Schematic sketch illustrating cortical reorganization patterns resulting from sensory deprivation and hearing restoration with a CI. All illustrated cortical changes are shown in comparison to the normally-matured auditory system (A). Different stages of sensory deprivation such as moderate hearing loss or deafness might induce various patterns of cortical changes (B, C, D). It is not well understood how these contribute to changes following sensory restoration with a CI (E, F, G). The (orange) vertical line patterns represent visual input, which is primarily processed in visual regions and the (blue) chequer patterns represent auditory processing which is primarily processed in auditory regions. The small amount of cross-modal processing which is generally found in NH individuals is not considered in this schematic illustration. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)