Cochlear-implants can be used to restore hearing in individuals with profound hearing loss. Currently, more than 200,000 otherwise deaf individuals are benefiting from this technology. However, there is a high degree of variability in performance outcomes across implant users. Our EEG study suggests that this variability is related to reorganisation within the auditory cortex. In particular, our results show that cochlear-implant users recruit the auditory cortex misleading to assist the processes involved in visual stimulation. This visual activation of the auditory cortex is more pronounced in individuals who have a moderate rather than a good ability to recognise speech. This cortical reorganisation appears to be maladaptive, as it may limit the capacity of the auditory cortex to adapt to the input supplied by the cochlear-implant. The present article summarises our study and sheds light on the role of EEG for the examination of cortical reorganisation in cochlear-implant users.

Introduction

Profound hearing loss usually cannot be cured, but cochlear-implants can restore hearing in affected individuals. Cochlear-implants transform acoustic signals into pulses of electrical current and directly stimulate the auditory nerve. Following implantation, cochlear-implant users need time to adapt to the artificial signal produced by the cochlear-implant. This is evidenced by the improved speech recognition ability and increased auditory cortex activity that accompanies prolonged cochlear-implant usage (Pantev et al., 2006). Experience with a cochlear-implant thereby leads to functional changes in the auditory system.

Functional changes in cochlear-implant users may not be limited to the auditory system, but may also affect other sensory systems. Deaf individuals exhibit better visual or tactile abilities compared with normal-hearing individuals (Bavelier et al., 2006). The neuronal basis of these performance improvements seems to be the reorganisation of the auditory cortex (Lomber et al., 2010). Accordingly, profoundly deaf individuals manifest activation in the auditory cortex in response to purely visual or vibrotactile stimulation (Merabet and Pascual-Leone, 2010). Cortical reorganisation in deaf individuals might be advantageous during the period of deafness, but could have detrimental consequences for the rehabilitation of hearing in an individual fitted with a cochlear-implant. Despite the restoration of acoustic signal input following implantation, cochlear-implant users may continue to recruit the auditory cortex for visual processing. Consequently, incomplete reversal of deafness-induced cortical reorganisation may limit the clinical benefit that can be derived from a cochlear-implant. In order to test this hypothesis, we performed an EEG study to examine visual processing in cochlear-implant users with moderate to good speech recognition ability (Sandmann et al., 2012). In particular, we applied a source analysis in order to study the recruitment of the visual and auditory cortex during visual information processing in these individuals.

EEG and the study of cortical reorganisation in cochlear-implant users EEG provides an objective measure of visual and auditory cortex functions in cochlear-implant users (Doucet et al., 2006; Debener et al., 2008; Viola et al., 2011). EEG is therefore a useful tool for studying cortical reorganisation in these individuals (Sandmann et al., 2009; Sandmann et al., 2010). While EEG has the drawback that it yields only moderate spatial information, alternative neuroimaging techniques appear even less feasible. Functional magnetic resonance imaging in particular is potentially invasive for cochlear-implant users (Giraud et al., 2001; Seghier et al., 2005; Majdani et al., 2008). Moreover, the use of whole-head magnetoencephalography is constrained by the strong electromagnetic interference induced by the cochlear-implant device (Pantev et al., 2006). These further limitations restrict the options for the study of cortical reorganisation to the use of EEG.

In our study we compared 12 post-lingually-deafened cochlear-implant users and 12 normal-hearing subjects. Four cochlear-implant users were implanted bilaterally and eight were implanted unilaterally either in the right ear (6 individuals) or the left ear (2 individuals). Each implant user
had been using their cochlear-implant continuously for at least 12 months prior to the experiment. The participants were presented with pairs of reversing chequerboard images on a computer screen (Figure 1) and were instructed to fixate on the centre of the images. The luminance ratio of each of the four chequerboard patterns varied systematically, corresponding to the presence of 12.5% (level 1), 25% (level 2), 37.5% (level 3), and 50% (level 4) white pixels in the chequerboard image. EEG data was continuously recorded from 63 Ag/AgCl sintered ring electrodes whose locations had been fixed in accordance with the 10-10 system. Specifically, we used an EasyCap cap (EasyCap, http://www.easycap.de/easycap) and two linked BrainAmp DC amplifiers (Brain Products, http://www.brainproducts.com/productdetails.php?id=2) to record any cortical activation that took place during visual information processing.

We compared the visual-evoked potentials (VEPs) for the cochlear-implant users with those for normal-hearing subjects in respect of the four chequerboard images. In addition to our analysis of EEG signals at the scalp sensor level, we applied a source estimation technique (sLORETA; Pascual-Marqui, 2002) in order to analyse the visual and auditory cortex activity generated by visual stimulation.

The results confirm a modulation of the P100 VEP amplitude as a function of the luminance ratio in the chequerboard images (Figure 2). A VEP modulation was found in both the cochlear-implant users and normal-hearing subjects; this is consistent with previous findings of larger VEP responses for higher luminance levels in the visual stimuli (Johannes et al., 1995). However, our results revealed smaller P100 amplitudes and reduced activation in the visual cortex for cochlear-implant users compared with normal-hearing subjects (Figure 2; Figure 3). This suggests that cochlear-implant users manifest functional changes in the central visual system as a consequence of altered auditory experience, in particular due to auditory deprivation and subsequent electrical input after implantation. Auditory experience (or the lack of it) may thus affect not only auditory but also visual functions in implant users (Doucet et al., 2006; Buckley and Tobey, 2011).

Conclusions

How can these findings be explained? Visual activation in the auditory cortex of cochlear-implant users might reflect a residual reorganisation of the auditory cortex. In particular, cortical reorganisation induced by sensory deprivation may not completely disappear after implantation, probably because the capacity for cortical reorganisation is limited (Bavelier et al.,...
2010). Accordingly, the visual activation of the auditory cortex may reflect an incomplete reversal of the deafness-induced cortical reorganisation. Cochlear-implant users may manifest a visual take-over type of reorganisation in the auditory cortex. This residual reorganisation appears to be maladaptive, and may in particular persist in those cochlear-implant users who have poor or moderate speech recognition abilities (Doucet et al., 2006; Buckley and Tobey, 2011).

Many cochlear-implant users benefit from having a cochlear implant. Nevertheless, there is substantial variability in performance outcomes across implant users (Moore and Shannon, 2009). While some of them achieve almost unlimited speech ability, others derive only minimal benefit from the implant. The results of our study suggest that this variability in performance outcome is related to the reorganisation of the auditory cortex. Cochlear-implant users recruit the auditory cortex to serve purely visual stimulation, suggesting that the auditory cortex is reorganised by the sense of vision in these individuals. This reorganisation seems to be more pronounced in cochlear-implant users who have poor or moderate as compared to good speech recognition ability. Reorganisation of the auditory cortex by the sense of vision might therefore have beneficial effects during the period of deafness, but an incomplete reversal of this cortical reorganisation may limit the clinical benefit that a cochlear-implant can provide. In particular, residual cortical reorganisation might reflect a maladaptive process in which the ability of the auditory cortex neurons to adapt to the input from the cochlear-implant is impeded. This interpretation is supported by the observation that individuals with more pronounced cortical reorganisation prior to implantation are less likely to benefit after implantation (Lee et al., 2001; Lee et al., 2007).

**References**


