International Journal of Pediatric Otorhinolaryngology 78 (2014) 737–743

Contents lists available at ScienceDirect

International Journal of Pediatric Otorhinolaryngology

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

Neuroelectrical imaging investigation of cortical activity during listening to music in prelingually deaf children with cochlear implants

Pasquale Marsella [a], Alessandro Scorpecci [a,*], Giovanni Vecchiato [b], Anton Giulio Maglione [c], Alfredo Colosimo [c], Fabio Babiloni [b]

[a] Otorhinolaryngology Department, Audiology and Otology Unit, Bambino Gesù Pediatric Hospital, Rome, Italy
[b] Department of Physiology and Pharmacology, University Sapienza, Rome, Italy
[c] Department of Anatomy, Histology, Forensic Medicine and Orthopedics, University Sapienza, Rome, Italy

ARTICLE INFO

Article history:
Received 21 November 2013
Received in revised form 20 January 2014
Accepted 22 January 2014
Available online 12 February 2014

Keywords:
Cochlear implant
Children
Prefrontal cortex
Music
Brain
EEG

ABSTRACT

Objective: To date, no objective measure of the pleasantness of music perception by children with cochlear implants has been reported. The EEG alpha asymmetries of pre-frontal cortex activation are known to relate to emotional/affective engagement in a perceived stimulus. More specifically, according to the "withdrawal/approach" model, an unbalanced de-synchronization of the alpha activity in the left prefrontal cortex has been associated with a positive affective state/approach toward a stimulus, and an unbalanced de-synchronization of the same activity in the right prefrontal cortex with a negative affective state/withdrawal from a stimulus. In the present study, High-Resolution EEG with Source Reconstruction was used to compare the music-induced alpha asymmetries of the prefrontal cortex in a group of prelingually deaf implanted children and in a control group of normal-hearing children.
Methods: Six normal-hearing and six age-matched deaf children using a unilateral cochlear implants underwent High-Resolution EEG recordings as they were listening to a musical cartoon. Musical stimuli were delivered in three versions: Normal, Distort (reverse audio flow) and Mute. The EEG alpha rhythm asymmetry was analyzed: Power Spectral Density was calculated for each Region of Interest, together with a right-left imbalance index. A map of cortical activation was then reconstructed on a realistic cortical model.
Results: Asymmetries of EEG alpha rhythm in the prefrontal cortices were observed in both groups. In the normal-hearing children, the asymmetries were consistent with the withdrawal/approach model, whereas in cochlear implant users they were not. Moreover, in implanted children a different pattern of alpha asymmetries in extrafrontal cortical areas was noticed as compared to normal-hearing subjects.
Conclusions: The peculiar pattern of alpha asymmetries in implanted children's prefrontal cortex in response to musical stimuli suggests an inability by these subjects to discriminate normal from dissonant music and to appreciate the pleasantness of normal music. High-Resolution EEG may prove to be a promising tool for objectively measuring prefrontal cortex alpha asymmetries in child cochlear implant users.

1. Introduction

Modern cochlear implants (CI) can restore optimal levels of speech comprehension in pre- and postlingually deaf subjects, but often fail to provide an acceptable music perception even in star performer recipients [1–3]. Postlingually deaf implanted subjects often complain about music sounding incomprehensible and unpleasant, and obtain lower scores than normal-hearing (NH) subjects when tested on the ability to discriminate the main spectral components of music, such as pitch, melody and timbre [4,5]. These difficulties can be attributed to a number of factors: technical limitations of modern CIs, for instance, do not allow an adequate representation of spectral and fine-temporal features of music, and provide a much narrower dynamic range as compared to acoustic hearing [3,4]. Auditory nerve degeneration is another important cause of altered music perception by implanted subjects.

Like adults, prelingually deaf children with cochlear implants show poorer pitch and melody discrimination skills than their normal-hearing peers [6–9]. Nonetheless, they seem to enjoy

* Corresponding author at: Audiology and Otology Unit, Bambino Gesù Pediatric Hospital, Piazza S. Onofrio 4, 00165 Rome, Italy. Tel.: +39 06 68592253; fax: +39 06 68592412.
E-mail address: alessandroscorpecci@yahoo.it (A. Scorpecci).

0165-5876/$ – see front matter © 2014 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijporl.2014.01.030

music listening and are often engaged in musical activities both in school and in leisure time, possibly because they have no musical memory as a reference. Such an apparent inconsistency suggests that beside discrimination and identification skills, the emotional/affective element is so important in the experience of music listening as to be the predominant factor underlying the overall enjoyment of music by child CI users [10]. As a consequence, any study of music perception in these subjects must include an assessment of the intrinsic pleasure generated by music listening. The self-reported subjective rating systems are inadequate to convey reliable information on this topic, especially if applied to very young, prelingually deaf subjects. Over the past two decades, neuroimaging research has investigated on objective measures of the emotional/affective engagement of the brain in complex tasks. Several techniques have been used to the purpose, such as PET, functional MRI and infrared spectroscopy, but High-Resolution Electro-Encephalography (HR-EEG) has been increasingly used thanks to its low cost and non-invasive application. The EEG is characterized by a high temporal resolution (<1 ms), which enables the measurement of the temporal evolution of the electric signals in the brain as well as the oscillatory and synchronized activity (neural signals on a fast time scale). Limits intrinsic in EEG include its inability to measure the cerebral activity of deep nuclei (e.g. amygdala, hippocampus, etc.) and its low spatial resolution. This latter drawback has partially been overcome by means of Source Reconstruction algorithms that use MRI-derived realistic head models in order to map the electrical activity on the cortex.

Several studies conducted in the last 20 years have used HR-EEG with Source Reconstruction to investigate the cerebral activity underlying the pleasantness of an individually experienced visual or auditory perception. Indirect variables of emotional processing can be gathered by tracking variations of the activity of specific anatomical structures linked to the emotional processing in humans [11]. Alpha activity has been most frequently used to detect inter- and between-subjects asymmetries in cortical activation, and the frontal lobes have been the most extensively studied areas, because they are involved in a number of executive functions such as working memory, temporal sequencing, creating expectations, anticipating outcomes, and planning actions to obtain rewards [12,13]. In particular, the prefrontal cortex (PFC) appears to be an integrating part of a larger overall circuit that implements emotional and motivational processes [14]. Research on EEG spectral power analyses suggests that the anterior cerebral hemispheres are differentially lateralized for approach and withdrawal motivational tendencies and emotions, according to the "withdrawal/approach" model [15]. Specifically, a relatively greater left PFC activity is associated with a general appetitive, approach, or behavioral activation motivational system, whereas a relatively greater right PFC activity relates to a tendency toward a general avoidance or withdrawal system [16–19]. In other words, left PCF activity indicates a propensity to engage in a stimulus, whereas right PFC activity relates to disengagement from a stimulus.

To date, very few neuroimaging studies have investigated how music activates the cortex of deaf individuals. One work employed PET to assess brain activation of post-lingual CI users [20], while no such investigation on deaf, implanted children has been conducted. In a recent pilot study, our research team demonstrated that it is possible to use HR-EEG to analyze the alpha asymmetries in the cortical activation of pediatric CI recipients during music listening [21].

The primary objective of the present research was to investigate HR-EEG alpha asymmetries in the PFC of a group of implanted children exposed to musical stimuli, and to compare them to a reference group of age-matched, normal-hearing children. The secondary objective was to investigate asymmetries in the activation of extrafrontal cortical areas in the same groups.

The main study hypothesis is that implanted children should exhibit a different pattern of music-induced PFC activation as compared to their normal-hearing peers, and that such a difference may be related to an unpleasant perception of music.

2. Methods

The procedures followed in the present study were approved by the Institution's Review Board and were in accordance with the Helsinki Declaration. Patients' parents signed a written informed consent for participation in the study.

2.1. Population

Twelve subjects were enrolled: six NH and six prelingually deaf children using a unilateral CI. Mean age of the participants was 43 ± 7.4 months for the NH group and 47.8 ± 19.8 months for the CI group. Gender distribution was three F and three M in the NH group, four F and two M in the CI group. Demographic and clinical data of the deaf children are described in Table 1. Implanted children were using a Cochlear® (Sydney, Australia) Nucleus™ implant, either a CI500™ ($n = 4$) or a Freedom™ series ($n = 2$) implant with a CP810™ processor. Basic map parameters were 25 µs pulse width, 900 pulses per second stimulation rate and ACE strategy in all subjects.

None of the children were engaged in formal musical training at the time of the study, which could have biased results because of the well-known differences in the activation of musicians' brain cortex as compared to non-musicians'.

On the day the EEG recordings were acquired, the study subjects underwent warble-tone free-field audiometry and a speech recognition evaluation to confirm their hearing and speech abilities were good. Implanted children received speech processor fitting if necessary, based on ECAP measurements and behavioral free-field audiometry with the CI.

2.2. Stimuli

Audiovisual stimuli consisted of a 4-min piece of the cartoon Fantasia (Walt Disney, 1940) accompanied by the original music of D. Paradisi. This excerpt was chosen because none of the children in the study had ever watched it (according to their parents) and because music plays a crucial role in the overall impact of the cartoon.

Three versions of the video-clip were delivered to each subject: the original video plus the original music (Normal condition); the original video and a distorted and unpleasant version of the music, obtained by reversing the audio flow and changing the pitch and the interval of the original music (Distort condition); the original video and no sound provided (Mute condition). Professional software for audio manipulation (Audacity, 2.0.4 version) was used. The acoustic sound pressure level presented was identical for the 4-min video in the Normal and Distort conditions. The order of stimulus delivery was randomized so as to remove the factor "sequence" as possible confounding effect. Before stimuli presentation, a 1-min "eyes open" (Rest) sequence was acquired.

Table 1
Demographic and clinical characteristics of cochlear implant users.

Pt.	Gender	Age (mo)	Age at CI (mo)	Etiology of deafness	Side of CI
1	F	41	17	Connexin 26 gene mutation	R
2	M	42	23	Antibiotic ototoxicity	R
3	F	30	27	Unknown	R
4	F	78	50	Unknown	L
5	M	66	21	Prematurity	R
6	F	30	72	Unknown	R