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EEG frontal asymmetry related to pleasantness of music perception in healthy children and cochlear implanted users

G. Vecchiato, A.G. Maglione, A. Scorpecci, P. Malerba, P. Marsella, G. Di Francesco, S. Vitiello, A. Colosimo, Fabio Babiloni

Abstract— **Interestingly, the international debate about the quality of music fruition for cochlear implanted users does not take into account the hypothesis that bilateral users could perceive music in a more pleasant way with respect to monolateral users. In this scenario, the aim of the present study was to investigate if cerebral signs of pleasantness during music perception in healthy child are similar to those observed in monolateral and in bilateral cochlear implanted users. In fact, previous observations in literature on healthy subjects have indicated that variations of the frontal EEG alpha activity are correlated with the perceived pleasantness of the sensory stimulation received (approach-withdrawal theory). In particular, here we described differences between cortical activities estimated in the alpha frequency band for a healthy child and in patients having a monolateral or a bilateral cochlear implant during the fruition of a musical cartoon.**

The results of the present analysis showed that the alpha EEG asymmetry patterns observed in a healthy child and that of a bilateral cochlear implanted patient are congruent with the approach-withdrawal theory. Conversely, the scalp topographic distribution of EEG power spectra in the alpha band resulting from the monolateral cochlear user presents a different EEG pattern from the normal and bilateral implanted patients. Such differences could be explained at the light of the approach-withdrawal theory. In fact, the present findings support the hypothesis that a monolateral cochlear implanted user could perceive the music in a less pleasant way when compared to a healthy subject or to a bilateral cochlear user.

I. Introduction

Most cochlear implant users report difficulties with music perception even after many years of implant usage [1-3]. This seems due to the fact that the signal processing of the cochlear device provides only limited spectral information and produces a much narrower dynamic range than acoustic hearing [3-4]. Limitations in the appreciation of the timbre and pitch of musical tones sequences have been reported in cochlear implant users when compared with normal hearing subjects. However, beyond these objective characteristics of sounds, there are diverse components that are also important in the experience of listening to music. These include subjective quality, mood and situational context. It is out of doubt that an acceptable music perception is important for the related increase in quality of life of cochlear implanted users.

One of the main problems with the fruition of such a complex stimulus, as the perception of music, is the assessment of the intrinsic pleasure derived from the listening. The self-reported psychological scales are often inadequate to convey precise information about the cerebral processing related to the pleasantness of the perceived music. However, in these last years, an objective measure of the cerebral activity has been put in strict relation with the pleasantness of an individual experienced perception.

In fact, indirect variables of emotional processing could be gathered by tracking variations of the activity of specific anatomical structures linked to the emotional processing activity in humans, such as the prefrontal and frontal cortex (PFC and FC respectively; [5]). The PFC region is structurally and functionally heterogeneous but its role in the generation of the emotions is well recognized [6]. EEG spectral power analyses indicate that the anterior cerebral hemispheres are differentially lateralized for approach and withdrawal motivational tendencies and emotions. Specifically, findings suggest that the left PFC is an important brain area in a widespread circuit that mediates appetitive approach, while the right PFC appears to form a major component of a neural circuit that instantiates defensive withdrawal (approach-withdrawal theory) [7,8]. It has been observed in literature a precise link of such theory with the unbalance of EEG spectra in alpha band on the prefrontal cortex [7-8].

The aim of the present pilot study is then to apply the analysis and a representation of the alpha EEG rhythms to monitor the perceived pleasantness obtained during the observation of a cartoon in a couple of users who received a monolateral and a bilateral cochlear implant, respectively, and in a healthy child. In particular, we presented the videoclip with the appropriate music (NORMAL), a distorted version of the music (DISTORT) and without music (MUTE). Results of this pilot study showed that, on the base of already validated literature on EEG frontal imbalance [7-8], the fruition of music and video, in terms of pleasantness, is higher in the healthy child and in the

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G. Vecchiato is with the Dept of Physiology and Pharmacology, University of Rome "Sapienza", Italy (e-mail giovanni.vecchiato@uniroma1.it). A.G. Maglione and A. Colosimo are with Department of Anatomy, Histology, Forensic Medicine and Orthopedics, University of Rome "Sapienza", Italy. P. Marsella and A. Scorpecci are with Centro Impianti Cocleari, Ospedale Pediatrico "Bambino Gesù" - IRCCS Piazza Sant'Onofrio, 4 - 00165 Rome. P. Malerba is with Cochlear Italia s.r.l.. G. Di Francesco and S. Vitiello are with IRCCS Fondazione Santa Lucia, Rome, Italy. F. Babiloni is with University of Rome "Sapienza" and IRCCS Fondazione Santa Lucia, Via Ardeatina 354, 00179, Rome, Italy (e-mail: Fabio.Babiloni@uniroma1.it).

bilateral implanted user when compared to the monolateral implanted one. Although this is just a pilot study, the application of the presented methodology is appropriate to investigate the subtle issue of the "perceived" pleasantness of music by cochlear implanted users in a near future.

II. Material and Methods

A. Experimental design

Two cochlear implanted users have been recruited for this pilot experiment. Informed consent was obtained from the parents of such users after the explanation of the study. User 1 (subject MCI) was a 6 year-old girl affected by bilateral profound, prelingual sensorineural hearing loss of unknown etiology. She underwent left-sided cochlear implantation surgery (CI model: Nucleus® CI24R Contour Advance) in September 2009, when she was 50 months old. Her Freedom™ speech processor was activated in October 2009, so that at the time EEG recordings were taken she had 28 months' length of CI use. User 2 was a 9 year-old girl (subject BCI), who rapidly became bilaterally deaf after pneumococcal meningitis at age 8. She successfully received a simultaneous bilateral cochlear implant (CI512 model) 6 weeks after the onset of meningitis, before cochlear ossification could occur. At the moment this study was conducted, she had been using her cochlear implant for 12 months. Both users had been using Cochlear™ Nucleus® CP810 speech processors with an ACE (Advanced Combination Encoder) strategy since hook-up and were provided with the same pre-processing strategies. In the month before EEG registration, both users had their cochlear implant controlled and mapped with a mixed behavioral and objective method, and received a warble-tone free-field audiometry and a comprehensive speech perception and recognition assessment. Both of them had all CI electrodes active with normal impedance levels, and were using an ACE strategy, a 900 pps stimulation rate and an ADRO (Adaptive Dynamic Range Optimization) pre-processing algorithm.

During EEG recordings they were allowed to adjust the volume of their speech processor microphones as they pleased.

The healthy child was a 9 year-old boy (subject CTRL) with no personal history of neurological or psychiatric disorder and he was free from medications.

The video stimulation was composed by a piece of 4 minute length of the cartoon Fantasia (Walt Disney, 1940) in which the original music of D. Paradisi was included. Such stimulus was chosen because the music plays an important role for the fruition of the cartoon, more than in the usual ones. Three versions of the videoclip were proposed to the users. Firstly, the original video plus the original music included (NORMAL condition). Secondly, the original video and a distorted and unpleasant version of the music (DISTORT condition). Third, the original video and no sound provided (MUTE condition). The DISTORT condition was obtained by reversing the flow of the audio, and changing linearly during the time the pitch and the interval of the original music. Professional software for audio manipulation was used. The acoustic pressure provided for all the 4 minutes video was identical for NORMAL and DISTORT conditions. Since this is a pilot study on only two users, we had no possibility to randomize the proposed sequence of stimulation across groups, and presented the same sequence (NORMAL, DISTORT and MUTE) to both users. In order to provide clues to the researcher about children's attention during the administration of the videos, users were then interviewed at the end of each piece to analyze attention and memory concerning the events included in the cartoon.

B. EEG recordings and signal processing

On the day the registration was performed, users both received a warble-tone free-field audiometry and a speech audiometry to make sure their hearing and speech recognition abilities were good. For the EEG data acquisition, all the subjects were comfortably seated on a chair, in an electrically-shielded, dimly-lit room. A EEG system (BEPlus, EBNeuro spa, Italy) at a sampling rate of 256 Hz was used to record electrical potentials by means of an electrode cap, according to an extension of the 10-20 international system.

In such a case, we considered for the analysis only the following channels: Af7, Af8, F3, Fz, F4, T7, C3, Cz, C4, T8, P3, Pz, P4, O1, O2. The EEG signals have been band pass filtered at 1-45 Hz and depurated of ocular artefacts by employing the Independent Component Analysis (ICA), manually after visual inspection. The recording sessions have been segmented in order to analyze the EEG activity elicited during the NORMAL, DISTORT and MUTE conditions. The EEG traces related to our datasets of interest have been further segmented in several EEG trials with a length of one second each. Later, a semi-automatic procedure has been adopted to reject trials presenting muscular and other kinds of movement artifacts. Only artifacts-free trials have been considered for the following analysis. Individual Alpha Frequency (IAF) has been calculated for each subject in order to define our band of interest according to the method suggested in the scientific literature [9-14]. Such band is in the following reported as IAF+x, where IAF is the Individual Alpha Frequency, in Hertz, and x is an integer displacement in the frequency domain which is employed to define the alpha band as (IAF-4, IAF+2), i.e. the frequency band between IAF-4 and IAF+2 Hz. The scalp EEG power spectral density (PSD) has been calculated by means of the Welch method [12-14] for each segment of interest and then averaged the spectral values in the alpha range to obtain a scalar object to analyze. To study the EEG frontal activity in the frequency band of interest of each electrode, we compared the three subjects' NORMAL spectral activity against the DISTORT one by employing the Student's t-test and the related False Discovery Rate (FDR) correction for multiple statistical comparisons. Similarly, we compared the DISTORT activity against the MUTE one. The corrected t-values are then spherically interpolated with the scalp surface in order to map the result on the head model. To protect child's privacy, the head model used for the representation of the estimated EEG scalp power spectra was relative to an adult's head. In the present work we report the most significant result of the analysis.

III. Results

A. Contrast between NORMAL and DISTORT conditions

In Fig.1 the color scale on the scalp surface codes the statistical significance: where there are scalp areas in which the power spectrum does not differ between the NORMAL and the DISTORT conditions, a grey color was employed. The red (blue) color highlights scalp areas presenting a statistically significant power spectral activity greater (lower) in the NORMAL condition than in the DISTORT condition. In particular, this information is provided for the healthy child (CTRL), bilateral (BCI) and monolateral cochlear implanted users, respectively.

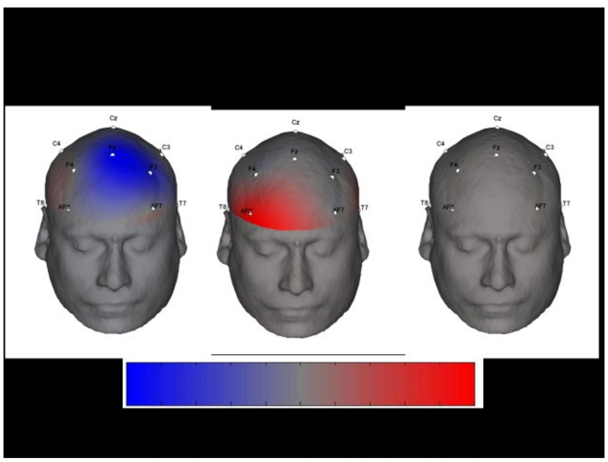

Fig. 1. Statistical scalp maps in the alpha band for the comparison between the normal observation of the cartoon with the appropriate music (NORMAL) and the observation of the same cartoon with the distorted music (DISTORT) for a healthy child (CTRL), a bilateral (BCI) and a monolateral (MCI) cochlear implanted user, respectively. Colorbar shows in red (blue) the scalp regions in which there is an increased statistically significant activity during the normal (distorted) fruition of the videoclip, estimated with a statistical significance of 5% (FDR corrected, as the symbol * indicates). Frontal view of the map is displayed.

The blue area in the frontal left hemisphere for the CTRL subject indicates a synchronization of the alpha rhythm for the DISTORT condition. As to the BCI subject, instead, a large scalp area of red activity can be appreciated. Such area indicates that in the prefrontal right scalp region it was estimated a synchronization of the alpha rhythm during the observation of the NORMAL cartoon with respect to the observation of the videoclip with the dissonant sound (DISTORT). This asymmetrical spectral activation, observed in both subjects analyzed, was also seen in the comparison between the NORMAL and DISTORT condition.. The large scalp PSD activations are still statistically significant after the use of the FDR correction, in order to prevent the statistical significance due to the execution of multiple t-tests. It is worth noticing that in the same experimental condition the user with the monolateral cochlear implant (MCI) does not present statistically significant scalp activations. Remarkably, here the topographical PSD related to the unilaterally implanted patient does not show any EEG frontal asymmetry.

B. Contrast between DISTORT and MUTE conditions

Fig.2 reports the results obtained by comparing the DISTORT against the MUTE condition for the healthy child (CTRL), the bilateral (BCI) and the monolateral cochlear implanted users, respectively. The significant enhance of alpha activity for the CTRL subject in the left frontal hemisphere produced a frontal EEG imbalance which is still congruent with the pleasantness theory described previously. As to the activity of the bilateral user (BCI), a frontal asymmetry is also present in terms of a synchronization of the alpha rhythm in right scalp sites. As far as it concerns the monolateral patient (MCI), it can be noticed that the alpha power spectrum is similar across the frontal and prefrontal areas in the two experimental conditions.

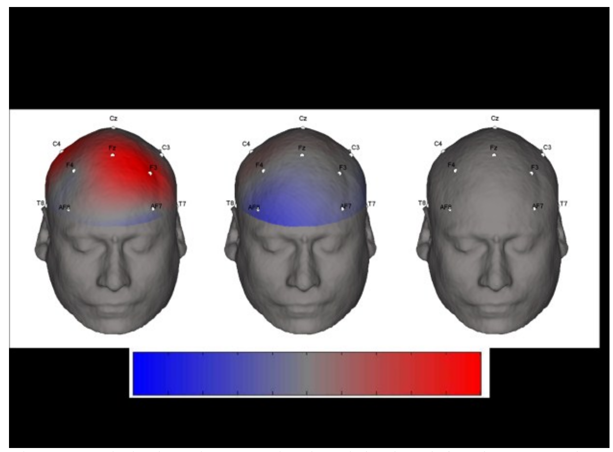

Fig. 2. Statistical scalp maps in the alpha band for the comparison between the distort observation of the cartoon with the distort music (DISTORT) and the observation of the same cartoon with no music (MUTE) for a healthy child (CTRL), a bilateral (BCI) and a monolateral (MCI) cochlear implanted user, respectively. Colorbar shows in red (blue) the scalp regions in which there is an increased statistically significant activity during the distorted (mute) fruition of the videoclip at 5% of significance (FDR corrected, as the symbol * indicates). Frontal view of the map is displayed.

IV. Discussion

In the present study an approach to the estimation of pleasantness of the perceived music has been presented by using the topographical distribution of EEG power spectra in the alpha bands. In particular, we analyzed the EEG activity of each of three different subjects (CTRL, BCI, MCI) in three experimental conditions (NORMAL, DISTORT, MUTE). Results obtained suggested significant differences "between-conditions", subject by subject. They show statistical difference in different tasks for two out of three subjects: CTRL is characterized by a modulation of alpha PSD at frontal sites (Fz, F3) whereas BCI shows differences at AF8. As stated above, we are not comparing the CTRL activity against the BCI one but describing differences resulting from comparisons of conditions for each subject.

According to the different spectral EEG statistical maps, the results of the present pilot study suggest that the healthy subject and the bilateral cochlear implanted user experienced more pleasant stimuli if compared to those perceived by the monolateral implanted user. This was indicated by the significant synchronization of alpha activity that was observed in the right prefrontal areas during the fruition of the NORMAL cartoon when compared to the DISTORT one. Instead, the healthy child presents a significant de-synchronization of the alpha rhythm on the left frontal regions in the same experimental condition. This is consistent with EEG frontal asymmetry theory which has been also observed in an our study on healthy subjects watching TV commercials [15]. Moreover, the same subjects also showed analogous differences in the power spectra of their EEG rhythms during the direct comparison of MUTE and DISTORT conditions. The user with a monolateral cochlear implant, instead, showed no imbalance of alpha power spectrum in the prefrontal areas in the NORMAL condition with respect to the DISTORT one, and in the DISTORT against MUTE condition. In addition, in the latter comparison there is no statistical difference. This result suggests that the monolateral cochlear implanted patient could not appreciate in full the difference in pleasantness for the auditory stimulation as the bilateral one does between the DISTORT and MUTE condition. A possible interpretation is that the perception of the music or quality of sound is not sufficiently contrasted, among the two conditions, to elicit a robust and statistically significant asymmetrical power spectrum response in the alpha band. However, these two patients present a different insurgence of the deftness. A previous research also found that resting EEG alpha asymmetry over frontal electrode sites predicts evaluations of affective musical stimuli [16]. These results are also congruent with a previous analysis performed by means of the high resolution EEG techniques [17]. At the moment, it is possible to hypothesize that this might be related to a poor fruition of music, although such a conjecture needs to be supported by a more robust experimental sample. In addition, the inverse alpha power activities between CTRL and BCI are both congruent with the frontal EEG asymmetry stated by Davidson [7]. For subject CTRL the left hemisphere is more activated, while it is the opposite for subject BCI, i.e. the right hemisphere is more responsive to the task. Results show that a de-synchronization of the alpha rhythm in frontal left areas is correlated to the observation and perception of pleasant stimuli. In such a case the inversion of the alpha power trend should be deeper investigated. Finally, both cochlear implanted users are females whereas the healthy subject is male. Due to the small experimental sample we are not able to take into account gender influences.

However, the results of this pilot study does not reject the hypothesis that EEG techniques may be useful to address the issue of music perception and its pleasantness in cochlear implanted patients.

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