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Investigation on the pleasantness of music perception in monolateral and bilateral cochlear implant users by using neuroelectrical source imaging: a pilot study

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Abstract— **There is a debate in the specialized literature about the quality of fruition of music for patients that received a cochlear implant. Interestingly, very few studies have investigated the hypothesis that patients that use a bilateral cochlear implant could perceive the music in a more pleasant way as compared to unilaterally implanted patients. Previous observations in healthy subjects have indicated that variations of particular EEG rhythms correlated with the pleasantness of the perceived music. The aim of the present pilot study is then to apply the state of the art neuroelectrical imaging and the analysis of cortical representation of EEG rhythms to monitor the perceived pleasantness during the observation of a simple videoclip in one patient with a unilateral cochlear implant and in one receiving a bilateral cochlear implant. Results of this pilot study showed that on the base of such previously validated EEG rhythms, the fruition of music and video, in terms of pleasantness, is statistically higher in the bilaterally implanted patient when compared to the monolateral implanted patient.**

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 sequences of musical tones have been reported in cochlear implant patients 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 implant patients.

One of the main problems with the fruition of so complex an event, as the perception of a music is the assessment of the intrinsic pleasure derived from such 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 decade, an objective measure of the cerebral activity has been put in strict relation with the pleasantness of the perception experienced by an individual. In particular, it has been observed that an increased spectral power in the central prefrontal cerebral cortex, called "frontal midline theta", could be associated to an increase of the mental effort as well as to an increase of the pleasantness of the perceived stimulation [5-6]. Studies applying EEG/MEG source modeling on different (non-emotional) mental tasks provide converging evidence that dipoles within medial frontal cortex (MFC), especially within dorsal anterior cingulate cortex (ACC; BA 24/32), account for frontal midline theta activity recorded at the scalp [5-6]. The link between frontal midline theta and the activity in the anterior cingulate cortex is interesting since ACC is activated by pleasant music [7-8]. Finally, different findings have already stressed the link between the frontal theta and subjective scores of the pleasantness of the emotional experience. In addition, there is interest in evaluating if the patients who received a bilateral cochlear implant could perceive music in a more pleasant way when compared to the patients who received the cochlear implant monolaterally. Previous observations in healthy subjectss have indicated that variations of particular EEG rhythms correlate with the pleasantness of the perceived music.

The aim of the present pilot study is then to apply the state of the art neuroelectrical imaging and the analysis of cortical representation of EEG rhythms to monitor the perceived pleasantness obtained in the observation of the same videoclip in a couple of patients who received a monolateral and a bilateral cochlear implant. 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 such previously validated EEG rhythms, the fruition of music and video, in terms of pleasantness, is statistically higher in the bilateral implanted patient when compared to the monolateral implanted patient. 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

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cochlear implant users in a near future. We applied the neuroelectrical imaging to monitor the brain activity of a couple of patients with uni- and bilateral Cochlear implant (CI). The monitoring was performed as they were instructed to watch three different videoclips, consisting of a cartoon without music, one accompanied by the appropriate music and one accompanied by a distorted sound. In the following study, we showed the statistical differences of cortical spectral activity elicited in these two patients during the observation of the different videoclips proposed.

II. Methods

A. Experimental Design

Two children have been recruited for this pilot experiment. Informed consent was obtained from the parents of such subjects after the explanation of the study.

Patient 1 was a 12 year-old boy who developed bilaterally profound deafness progressively following congenital cytomegalovirus infection. His sensorineural hearing loss was mild at diagnosis (4 years) and got worser over the year until left-sided cochlear implantation (Cochlear™ Nucleus® CI512 model) was necessary at age 11. At the moment the measurements were taken, he had been using his cochlear implant for 12 months. Patient 2 was a 9 year-old girl, 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 patients had been using Cochlear™ Nucleus® CP810 speech processors with an ACE strategy since hook-up and were provided with the same pre-processing strategies. One month before EEG registration, both patients had their cochlear implant T- and C-levels fitted according to their subjective responses.

On the day the registration was performed, they 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 32-channel EEG system (BEPlus, EBNeuro spa, Italy) was used to record electrical potentials by means of an electrode cap, according to an extension of the 10-20 international system. High-resolution EEG technologies were developed to enhance the poor spatial information content of the EEG activity [9-11]. 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 piece from the video Fantasia was chosen since the music play an important role for the fruition of the cartoon, more than in the usual cartoon. Three version of the videoclip was proposed to the patients. First, 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 condition. Before all the EEG recordings a sequence of 1 minute to eye closed and 1 min of eye open was recorded in both subjects, to provide a baseline for the estimation of EEG spectra (REST condition). Since this is a pilot study on only two patients, we had no possibility to randomize the proposed sequence of stimulation across groups, and presented the same sequence (REST, NORMAL, DISTORT and MUTE) to both patients. Patients were then interviewed at the end of each piece to analyze attention and memory concerning the events included in the cartoon, in order to provide clues to the researcher about children's attention during the administration of the videos .

B. Estimation of cortical activity from EEG measurements

In this work, cortical activity from EEG scalp recordings was estimated by use of a realistic head model. This model consists of about 8.000 dipoles uniformly disposed on the cortical surface and the estimation of the current density strength for each dipole was obtained by solving the linear inverse problem according to techniques described in previous papers ([9-11]. In addition, the estimation of the cortical power spectral activity in different frequency bands was made in agreement with the procedure previously illustrated [9,10]. Statistical z-score maps will be presented in different frequency bands by using Bonferroni correction.

In this particular application, we considered as baseline the REST condition related to the situation open eye performed before the observation of the documentary. Here, we used an extended approach to the analysis of the power spectra variations during the experimental task as described in [10].

C. Contrast between different experimental conditions

The statistical significance of the power spectral values during the observation of the diffent experimental conditions analyzed was assessed by cortical maps. It will, however, be of interest also to describe the areas of cortical differences (if any) between the NORMAL and DISTORT dataset. In this case it could be of interest to analyze whether the levels of the variable considered for the characterization of brain activity (i.e. the EEG spectral power in the different frequency bands analyzed) differ between those particular experimental conditions in each particular patient analyzed. So far, a methodology for the generation of a statistical cortical distribution of Bonferroni-corrected z scores for each particular subject has been described. However, in order to present the results of the z-score contrasts between experimental conditions relative to analyzed subjects we need to use a realistic head model provided by the McGill University and largely used worldwide. Such realistic model of the cortical surface were used to display the cortical areas that are statistically significantly activated during the different experimental conditions in both the patients analyzed. Then, a voxel of such brain model was highlighted in light gray if it was not a cortical site in which a statistically significant variation of the spectral power between the investigated experimental conditions was found during the different observation of the videoclips by the patients. Otherwise, we depicted such brain voxels in red if such voxel was statistically significant, after Bonferroni correction for multiple comparison, as described above, at a effective level of statistical significance of $p < 0.005$.

D. Patterns of Power Spectral Density

The scalp neuroelectrical activity has been recorded with a 32-channel system (BEPlus, EBneuro Florence, Italy), with a sampling rate of 256 Hz. The EEG signals have been band pass filtered at 1-45 Hz and depurated of ocular artefacts by employing the Independent Component Analysis (ICA): the components due to eye blinks and ocular movements have been detected by eye inspection and then removed from the original signal. The recording sessions have been segmented in order to analyse the EEG activity elicited during the REST, NORMAL, DISTORT and MUTE conditions.

A semi-automatic procedure has been also adopted to reject trials presenting muscular and other kinds of artefacts. Only artefacts-free trials have been considered for the following analysis. All datasets have been transformed by means of a Common Average Reference (CAR) and the Individual Alpha Frequency (IAF) has been calculated for each subject in order to define six bands of interest according to the method suggested in the current scientific literature [10]. Such bands were in the following reported as IAF+x, where IAF is the Individual Alpha Frequency, in Hertz, and x is a integer displacement in the frequency domain employed to define the band. In particular we defined: theta (IAF-6, IAF-4) i.e. theta ranges between IAF-6 and IAF-4 Hz, lower alpha 1 (IAF-4, IAF-2), lower alpha 2 (IAF-2, IAF), upper alpha (IAF, IAF+2), beta (IAF+2, IAF+14), gamma (IAF+14, IAF+30).

In this brief report we present only the cerebral activity estimated in the theta frequency band since it is related to the occurrence of the phenomena of pleasantness perceived and attention to the proposed stimuli.

III. RESULTS

A. Contrast between NORMAL and DISTORT conditions

In Fig.1 the colour scale on the cortical surface codes the statistical significance: where there are cortical areas in which the power spectrum does not differ between the two 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 patient who had the bilateral cochlear implant. The large zone of red activity can be appreciated, which means that in the prefrontal central cortical areas the power spectra is greater during the observation of the NORMAL videoclip than during the observation of the videoclip with the dissonant sound (DISTORT).

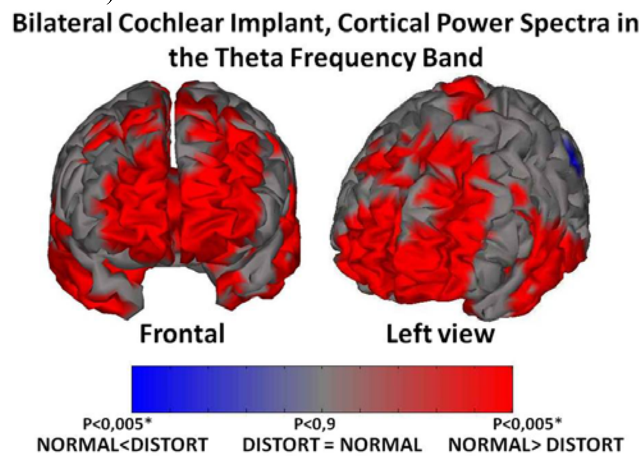

Fig. 1. Statistical cortical maps in the theta band for the comparison between the normal observation of the videoclip with the appropriate music and the observation of the same videoclip with the distorted music. The patient has a bilateral cochlear implant. Colorbar shows in red (blue) the cortical regions in which there is an increased (decreased) statistically significant activity during the normal (distorted) fruition of the videoclip. Frontal and left view of the cortex are displayed.

The large areas are significant after Bonferroni correction. In the same experimental condition the patient with the monolateral cochlear implant presents the statistically significant cortical activations, as described in Fig.2.

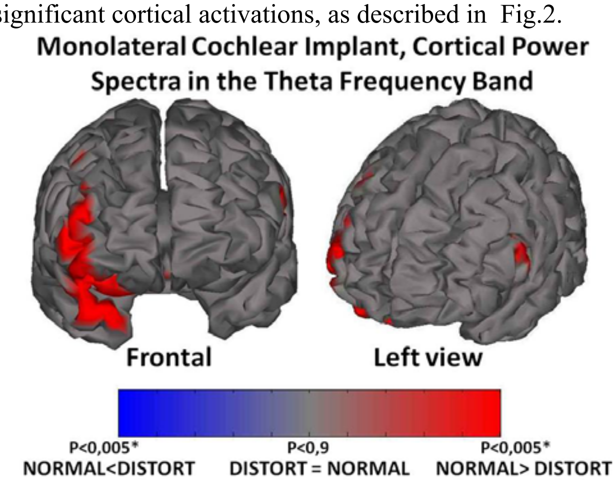

Fig. 2. Statistical cortical maps in the theta band for the comparison between the normal observation of the videoclip with the appropriate music and the observation of the same videoclip with the distorted music. The patient has a monolateral cochlear implant. Same conventions of the previous figure.

Remarkably, Fig. 2 shows that in the unilaterally implanted patient few areas of the cortex have stronger responses in the theta frequency band during the NORMAL rather than during the DISTORT condition. Such cortical areas of statistically increased power spectra are located in the right prefrontal cortex.

B. Contrast between DISTORT and MUTE conditions

Fig.3 reports the results obtained by comparing the DISTORT and MUTE conditions in the bilaterally implanted patient. It can be noticed that the power spectra in this frequency band seems similar across the prefrontal cortices in the two conditions. There is instead an increased spectral activity in the left temporal area in the MUTE condition.

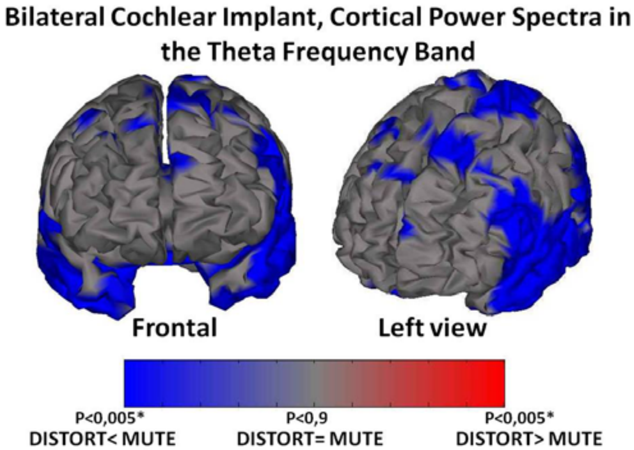

Fig. 3. Statistical cortical maps in the theta band for the comparison between the DISTORT and MUTE conditions. Same conventions as above. The patient has a bilateral cochlear implant.

Fig. 4 reports the contrast between the DISTORT and MUTE condition for the patient with the unilateral cochlear implant. In this case there are no differences between the power spectra in these two conditions in the theta frequency band.

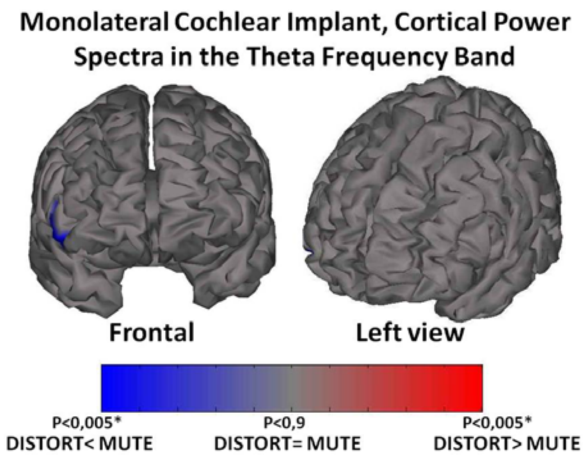

Fig. 4. Statistical cortical maps in the theta band for the comparison between the DISTORT and MUTE conditions. Same conventions as above. The patient has a monolateral cochlear implant.

IV. Discussion

In the present study an approach to the estimation of attention and pleasantness of the perceived music has been presented by using distributed source neuroelectrical imaging. The results of this pilot study seems to suggest that in the bilaterally implanted patient pleasantness of the correct perception of music is important. In fact, during the fruition of the NORMAL condition (i.e. the video with normal video and music associated) an increased activity was observed in the prefrontal areas in the theta band when compared to the other conditions (MUTE and DISTORT). This is consistent with the increased frontal midline theta spectral power that has been observed in normal hearing subjects during the perception of music. In addition, increased frontal midline theta has been also described as a sign of an increase of attention toward external cues. Moreover, the bilaterally implanted patient showed no particular differences in the power spectra of her EEG rhythms during the direct comparison of MUTE and DISTORT conditions. The patient with a monolateral cochlear implant instead showed a moderate increase of theta power spectra in the prefrontal areas in the NORMAL condition with respect to the DISTORT or MUTE condition. A possible interpretation is that the perception of the music or quality of sound is not sufficiently contrasted among the conditions to elicit increased power spectra responses in the analyzed theta band. 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. However, the results of this pilot study prove the usefulness of high-resolution EEG techniques and distributed neuroelectrical source imaging in order to address the issue of music perception and its pleasantness in cochlear implant patients.

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