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Differences in the perceived music pleasantness between monolateral cochlear implanted and normal hearing children assessed by EEG

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Abstract— **The perception of the music in cochlear implanted (CI) patients is an important aspect of their quality of life. In fact, the pleasantness of the music perception by such CI patients can be analyzed through a particular analysis of EEG rhythms. Studies on healthy subjects show that exists a particular frontal asymmetry of the EEG alpha rhythm which can be correlated with pleasantness of the perceived stimuli (approach-withdrawal theory). In particular, here we describe differences between EEG activities estimated in the alpha frequency band for a monolateral CI group of children and a normal hearing one during the fruition of a musical cartoon. The results of the present analysis showed that the alpha EEG asymmetry patterns related to the normal hearing group refers to a higher pleasantness perception when compared to the cerebral activity of the monolateral CI patients. In fact, the present results support the statement that a monolateral CI group could perceive the music in a less pleasant way when compared to normal hearing children.**

I. Introduction

Due to the limit of the cochlear device, many cochlear implanted users refer difficulties with music perception [1-3]. The difficulties are due to the limited spectral information provided by the device which produces a more narrow dynamic range than normal hearing [3,4]. By comparing normal hearing subjects with cochlear implanted patients, it has been observed that there are limitations in the evaluation of the timbre and pitch of musical tones sequences. In addition to these objective characteristics of sounds in the listening to the music, there are other factors that complete this kind of experience. Specifically, they are subjective quality, mood and situational context. A good music perception is important for increasing the quality of life of cochlear implanted users. The fruition of music falls inside the context of the perception of complex stimuli. In this field, one of the main problems is that the evaluation of the pleasantness strictly depends on the listening. In last decade, the pleasantness of an individually experienced perception has been correlated with an objective measure of the cerebral activity. This measure of pleasantness try to overcome the inaccurate information given from the self-reported psychological scales that is often inadequate for this kind of measure. By tracking the variations of the activity of specific anatomical structures linked to the emotional processing activity in humans, such as the pre- and frontal cortex (PFC and FC, respectively), indirect variables of emotional processing could be collected, [5]. The PFC region is structurally and functionally heterogeneous but its role in the generation of the emotions is well recognized. The anterior cerebral hemispheres, through EEG spectral power analyses, are differentially lateralized for approach and withdrawal motivational tendencies and emotions [6]. The left side of PFC is a significant 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.

The aim of the present study is to apply the approach-withdrawal theory of the EEG rhythms in order to inspect the perceived pleasantness during the observation of a musical cartoon. The experimental group is formed by children who received a monolateral cochlear implant. Their EEG activity has been compared with a control group. In particular, we presented the both groups a video-clip with the appropriate music, a distorted version of it and a stimulus without music. Results of this study showed that the fruition of music and video, in terms of cerebral indexes related to pleasantness and approaching situations, is higher in the normal hearing subject group. The application of this technique will be more deeply investigated in order to assess differences between groups at cortical level.

II. Material and Methods

A. *Experimental design*

Five monolateral cochlear implanted users (MCI group) and five normal hearing subjects (CTRL group) have been recruited for this pilot experiment. Informed consent was obtained from the parents of all of them after the explanation of the study. During the EEG data acquisition, subjects were comfortably seated on a chair, in an electrically-shielded, dimly-lit room. A 16-channel EEG system (BEPlus, EBNeuro spa, Italy) was used to record the electric potentials by means of an electrode cap. According to an extension of the 10-20 international system, we record the

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cerebral activity from Af7, Af8, F3, Fz, F4, T7, C3, Cz, C4, T8, P3, Pz, P4, O1, O2 sites.

The video stimulation, as reported in previous analyses [7,8], was composed by a part of four minutes of the Fantasia cartoon (Walt Disney, 1940) in which the original music of D. Paradisi was proposed. Such piece has been chosen since the music plays an important role in the cartoon, more than in a regular one. Three versions of the video-clip were watched by the subjects. Firstly, the original video plus the original music included (Normal); secondly, the original video and a distorted version of the music (Distort); thirdly, the original video and no sound inserted (Mute). The Distort condition was obtained by reversing the flow of the audio, linearly changing during the time the pitch and the interval of the original music. Professional software for audio manipulation was used (Audacity). The acoustic pressure provided for all the shown videos was identical for Normal and Distort condition. The video sequence has been randomly presented to the subjects. Before the stimuli presentation a sequence of one minute of eye closed and one minute of eye open (Rest) was acquired. Subjects were interviewed at the end of each type of the three experimental conditions to verify the levels of attention concerning the events included in the cartoon.

B. Subjects

The MCI group is composed by five young patients. Patient R.P. was a 6 year-old girl (age=6 ys, 7 mo) 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. Patient A.L. was a 3 year-old girl (age=3 ys, 5 mo) affected by bilateral profound, prelingual sensorineural hearing loss due to a homozygous GJB2 gene mutation. She received a right-sided cochlear implant (CI model: Nucleus ® CI512) in March 2010, when she was 18 months old. She started using her CP810™ speech processor in April 2010, so that at the time EEG recordings were taken she had 24 months of CI use. Patient R. C. was an apparently healthy girl until age 6 and a half, when she suffered from an idiopathic, rapidly progressive sensorineural hearing loss, which became bilaterally profound over a few weeks. Therefore, in February 2011 (at age 7) she underwent simultaneous, bilateral cochlear implantation (CI model: Cochlear Nucleus CI512); 4 months after implantation, she reported feeling discomfort when stimulated by the left CI; an integrity test documented a failure of her left CI. Thus, she was tested with her right CI only. Patient C.D.R. is a child born on the 5th July 2008 and she uses a cochlear implant on the right ear that was implanted on the 23rd March 2010 (CI model: Cochlear Nucleus CI512, CP810 processor). The cause of the deft is unknown. Nowadays the child is using the ACE strategy. Patient M.B., at the time of the recording, was 30 month-old girl with bilateral profound sensorineural hearing loss. She received right-side cochlear implant in February 2012 (at 27 months of age). The etiology of her hearing loss is unknown.

The CTRL group is composed by five aged matched (Student's t = 1.1, p=0. 8) young children with no history of hearing diseases.

C. Recording and signal processing

On the day the registration was performed, all the cochlear implant users received a warble-tone free-field audiometry and a speech audiometry to make sure their hearing and speech recognition abilities were good.

The EEG data have been acquired at a sampling rate of 256 Hz and the electrodes impedance were kept below 5Ω. The EEG signals have been band pass filtered (1-45 Hz) and reduced the effect of the ocular artifacts by using the Independent Component Analysis (ICA), manually removing the affected components, such as the artifact generated by the cochlear implant itself, after visual inspection. The recording sessions data have been segmented in order to analyze the EEG activity during the Rest, Normal, Distort and Mute conditions. The EEG traces were further segmented in trials with a length of one second each. Later, a semi-automatic procedure has been adopted to reject trials presenting artifacts due to movement or muscular activity. Only the last two minutes of the artifacts-free trials have been considered for the following analysis. Then, the EEG scalp Power Spectral Density (PSD) [9] has been calculated with the Welch method for each segment of interest. Then the spectral values have been averaged in the theta and alpha ranges. These bands are defined as IAF+x, where IAF is the Individual Alpha Frequency [10] and x is an integer displacement in the frequency domain which is used to define the theta band as IAF-6, IAF-4 and the alpha band as IAF-4, IAF+2 Hz.

D. Estimation of cortical activity

In this work, cortical activity from EEG scalp recordings was estimated by use of a realistic head model consisting in 8.000 dipoles uniformly disposed on the cortical surface. The estimation of the current density strength was obtained by solving the linear inverse problem according to techniques described in previous papers [11-13]. Statistical z-score maps will be presented by using Bonferroni correction. Here, we considered as baseline the REST condition.

E. Frontal imbalance

In order to investigate the cerebral frontal asymmetry, we calculated the following approach/withdrawal spectral imbalance index:

$$AW = PSD_R - PSD_L \quad (1)$$

$$AW_{Log} = \log(|AW|) * \mathrm{sgn}(AW) \quad (2)$$

where PSD_R and PSD_L stand for the Power Spectral Density calculated among frontal channels, on the right and left side respectively. The Right (R) channels are AF8 and F4, whereas the Left (L) ones are AF7 and F3. The average spectral activity has been calculated among right and left channels in the alpha band. According to the presented EEG frontal asymmetry theory, we used the spectral frontal imbalance as a metric to measure the emotional state of subjects [15] across the experimental conditions. Positive (negative) values of this index relate the perception of pleasant (unpleasant) stimuli. We took into account the logarithmic imbalance for each experimental condition (Normal, Distort, Mute).

D. Between subjects analysis

The spectral activity of the following areas Anterior (A), Central (C) and Posterior (P) has been compared. These macro areas are obtained by averaging the electrical activity of the respective areas. Namely, for the A macro area channels AF7, F3, F4, AF8, Fz have been used; for the C macro area we have channels T7, Cz, T8, C3, C4 and for the P macro area channels P3, O1, Pz, P4, O2 have been taken into account. These areas have been considered to perform a mixed analysis of variance (ANOVA) with between factor SUBJECTS [CTRL, MCI] and within factors CARTOON [Normal, Distort, Mute] x AREAS [Anterior, Central, Posterior]. The same kind of analysis was performed considering as the macro areas Left (L), Central (C) and Right (R). In this case, to define the L macro area channels AF7, F3, C3, T7, P3, O1 are used; channels Fz, Cz, Pz for the C area and sites AF8, F4, C4, T8, P4, O2 for the R one. In order to standardize the cerebral activations among subjects, the PSD values have been transformed into z-score by using the open eyes resting state dataset.

III. Results

Figure 1 illustrates the cortical activations of a representative monolateral implanted patient. 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). Remarkably, Fig. 1 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. Activations related to the control group are not reported for space limitations.

This imbalance of activations are also showed by the next results. Figure 2 presents the difference (Student's $t=10.9$, $p<0.0001$) in the time-varying waveform of the logarithmic spectral frontal imbalance, computed in the alpha band among frontal electrodes, related to the observation of the cartoon with normal audio for the two populations, i.e. normal hearing subjects (CTRL) and monolateral patients (MCI). The trend is the same for the Distort and Mute conditions as well.

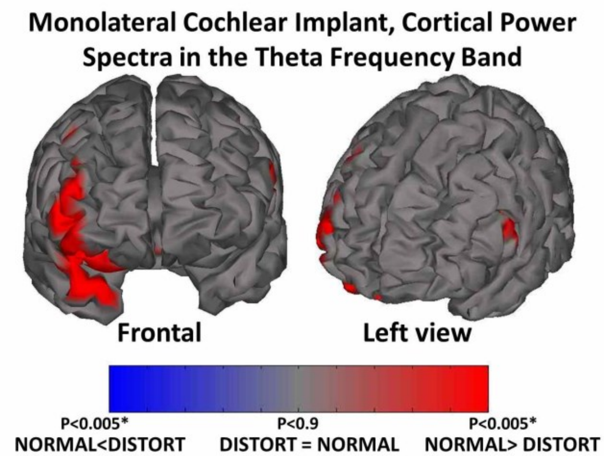

Fig. 1. Statistical cortical maps in the theta band for the comparison between the normal observation of the videoclip with the appropriate music and the observation of the same videoclip with the distorted music. The patient has a monolateral cochlear implant. Colorbar shows in red (blue) the cortical 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.

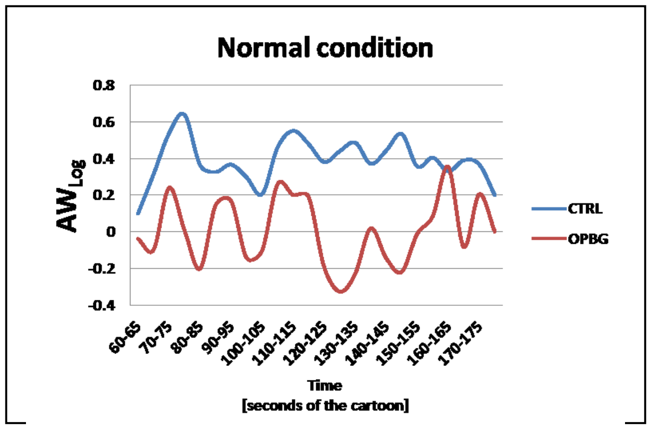

Figure 2. Logarithmic time-course of the spectral frontal imbalance in the alpha band for the two experimental populations (normal hearing subjects, CTRL – blue; monolateral cochlear implanted patients, MCI - red). The two signals span the last two minutes of the cartoon in the normal audio condition.

Figure 3 reports the ANOVA result in the alpha band (we observed the same trend for the theta band). The ANOVA results present a significant difference between the two populations [$F(1,8)=31.893$, $p<0.0001$] as well as regarding the factors AREA [$F(2,16)=89.519$, $p<0.0001$] and AREA*GROUP [$F(2,16)=23.349$, $p<0.0001$]. No statistically significant differences have been found for the factor CARTOON. All the pairwise comparisons for factors AREA and CARTOON returned statistically significant differences among levels ($p<0.05$).

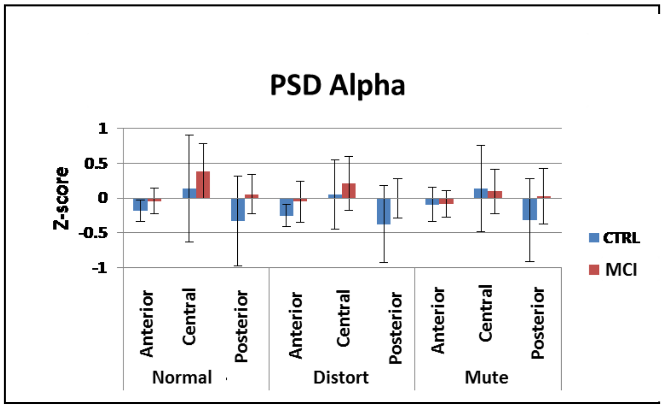

Figure 3. Average z-score PSD values of normal hearing subjects (CTRL) and monolateral cochlear implanted patients (MCI) related to the observation of the cartoon for the three experimental conditions (Normal, Distort, Mute) across scalp sites (Anterior, Central, Posterior).

The present results show cerebral activations discriminating the two populations. In particular, the normal hearing subjects present, on average, higher values of the frontal imbalance and larger variations of the PSD across scalp sites. However, the present findings do not show differences across different stimulations.

IV. Discussion

In the present study, an approach to the estimation of the perceived pleasantness during the fruition of audiovisual stimuli by monolateral cochlear implanted patients and normal hearing subjects has been presented. In particular, we performed a statistical spectral analysis by using an imbalance index, defined according to the approach-withdrawal theory [6], and investigated the average scalp activations in the alpha band by comparing the two experimental populations. The results of the present study suggest that the monolateral cochlear implanted patients present a pattern of activation different from that of normal hearing subjects as shown by the analysis of the imbalance index. The logarithmic imbalance values indicate that the cochlear implanted patient perceives in similar manner the audio in all the three conditions. However, these values are significantly lower than those measured among normal hearing subjects. As far as concern the statistical comparison of the average activations in the alpha band, we still observe a different pattern of spectral values among regions of interest between the two populations. These findings suggest that the healthy subjects have a more pronounced tendency to a state of relaxation while observing the cartoon, likely due to a better perception of classical music. The significant differences in the EEG activity may be due to the fact that the cochlear implanted patients could differently hear the music with respect to the normal hearing subjects. This difference in perception of music may not evoke the same emotional states of relaxation and pleasure in patients. These results are also congruent with a previous analysis performed by means of the high resolution EEG techniques [16].

The results of the present study prove the usefulness of the EEG techniques to address the issue of music perception and its pleasantness in cochlear implanted patients. In addition, the inverse alpha power activities between CTRL and MCI are both congruent with the frontal EEG asymmetry stated by Davidson [6]. For subject CTRL the left hemisphere is more activated, while it is the opposite for subjects MCI, 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.

Hence, the results of the present study do 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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