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# A preliminary EEG study to investigate the fruition of audiovisual stimuli between cochlear implanted patients and healthy subjects

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***Abstract.*** There are some studies, in the specialized literature, about the perception of the music in patient with cochlear implant. The music perception can be analyzed through emotions, such as the pleasantness. 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. The aim of the present pilot study is to compare the EEG frontal imbalance and scalp activities between cochlear implant patients and healthy subjects during the fruition of a musical cartoon. Results of the study showed that the pleasantness perceived during the fruition of audiovisual stimuli was higher in the monolateral cochlear implanted child when compared to the control one. The identification of some scalp areas could indicate the absence of the state of relaxation induced by listening to classical music in the cochlear patient.

*Keywords: EEG, frontal asymmetry, pleasantness, cochlear implant, frequency analisys*

## 1. Introduction

Due to the limit of the cochlear device, many cochlear implanted users refer difficulties with music perception [Gfeller et al., 2000; McDermott, 2004; Veekmans et al., 2009]. The difficulties are due to the limited spectral information provided by the device which produces a more narrow dynamic range than normal hearing [Veekmans et al., 2009; Galvin et al, 2007]. By comparing normal hearing subjects with cochlear implant patients 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 problems is that the evaluation of the pleasantness strictly depends on the listenering. In last years, 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 gave 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, [Davidson and Irwin, 1999]. 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 [Davidson, 2002]. The left side of PFC is an 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 to the EEG rhythms to inspect the pleasantness perceived during the observation of a musical cartoon in an user who received a monolateral cochlear implant and a healthy child. In particular, we presented the videoclip with the appropriate music, a distorted version of it and a stimulus without music. Results of this pilot study showed that the fruition of music and video, in terms of pleasantness, is higher in the cochlear child. Although this is only a pilot study, the application of this technique will be addressed in larger groups of patients and healthy children.

## 2. Material and Methods

### 2.1 Experimental Design

Two children have been signed up for this experiment. Informed consent was signed from the parents of such subjects before the EEG recording.

Patient 1 was a 12 year-old boy (subject MCI) who developed bilaterally profound deafness progressively following congenital cytomegalovirus infection. His sensorineural hearing loss was mild at diagnosis (4 years) and got worse over the year until left-sided cochlear implantation (Cochlear™ Nucleus® CI512 model) was necessary at age 11. He had been using his cochlear implant for 12 months. The patient had been using Cochlear™ Nucleus® CP810 speech processors with an ACE strategy since hook-up and were provided with the same pre-processing strategies. In the month before EEG recording, the patient had his cochlear implant T- and C-levels fitted according to his subjective responses. 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. At the day of the experiment, the patient 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, both 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 electrical potentials by means of an electrode cap, according to an extension of the 10-20 international system.

The video stimulation, as reported in previous analyses [Vecchiato et al., 2011, 2012], was composed by a part of four minute 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 in the cartoon, more than in a regular one. Three versions of the videoclip 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. The acoustic pressure provided for all the shown video was identical for Normal and Distort condition.

In order to have a baseline for the estimation of EEG signals, before the stimuli presentation a sequence of one minute of eye closed and one minute of eye open (Rest) was acquired for the two subjects,. Due to the small sample of experimental subjects, we had no possibility to randomize the proposed sequence of stimulation across children, se we presented the same sequence (Rest, Normal, Distort and Mute) to both of them. 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, in order to provide indications to the researcher.

### 2.2 EEG recording and signal processing

We considered for the analysis 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 (1-45 Hz) and reduced the effect of the ocular artifacts by using the Independent Component Analysis (ICA), manually removing the affected components after visual inspection. The recording sessions 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 EEG 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 muscularactivity. 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) [Welch, 1967] has been calculated with the Welch method for each segment of interest and then averaged the spectral values in the theta and alpha ranges. These bands are defined as IAF+x, where IAF is the Individual Alpha Frequency 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. The IAF frequency was calculated for each subject, in according to the existing method in the scientific literature [Klimesch et al., 1999], in order to define our band of interest.

### 2.3 Contrast between subjects

The statistical significance of the PSD values during the observation of the different experimental conditions was assessed by statistical scalp maps. To obtain the maps related to the statistical comparisons, the PSD values have been z-score transformed by using the Rest condition as baseline. The z-score values were calculated for each experimental condition , in each frequency band, of the two children through the Student t-test (e.g., Normal, CTRL vs MCI, in the theta band, $p < 0.05$). The False Discovery Rate (FDR) correction was performed after all statistical tests . Further, we examined the spectral activity of the following areas Anterior (A), Central (C) and Posterior (P). 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 three-way analysis of variance (ANOVA) with factors Subject [CTRL, MCI] x Film [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.

### 2.4 Frontal Spectral Imbalance

In order to investigate the cerebral frontal asymmetry, we calculated the following spectral imbalance:

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

$$IM\ Log = \log(|IM|) * sgn(IM) \quad (2)$$

Where

IM = Imbalance Index

$PSD_R$, $PSD_L$ = Power Spectral Density calculated across frontal channels. The Right (R) channels are AF8 F4, whereas the Left (L) ones are AF7 F3

IM Log = Base 10 Logarithmic Imbalance Index

The average spectral activity has been calculated among right and left channels in Alpha band. According the EEG frontal asymmetry theory presented above, this index has been defined such that positive (negative) values are related to left (right) alpha de-synchronization (synchronization). Positive (negative) values of this index indicate the perception of pleasant (unpleasant) stimuli. The spectral imbalance (IM) has been calculated for both the recorded subjects in the three experimental conditions. We considered the logarithmic IM for each experimental condition (NORMAL, DISTORT, MUTE) and then we calculated and compared the percentage of time in which the IM is above zero, which is a measure correlated with the pleasantness perceived in the tested conditions along the entire duration of the presented cartoons.

## 3. Results

### 3.1 Comparison between subjects

In Fig. 1, the statistical comparison between subjects can be observed in one experimental condition, in theta and alpha band. Statistically significant differences across scalp areas are shown in the Normal and Mute conditions. As to the Normal condition, in theta band, an enhance of spectral activity for CTRL (blue areas) emerges in central and posterior scalp areas. As to the Mute condition, in the alpha band, we noted that the enhance of the PSD for CTRL is related to the frontal and posterior left sides of the scalp.

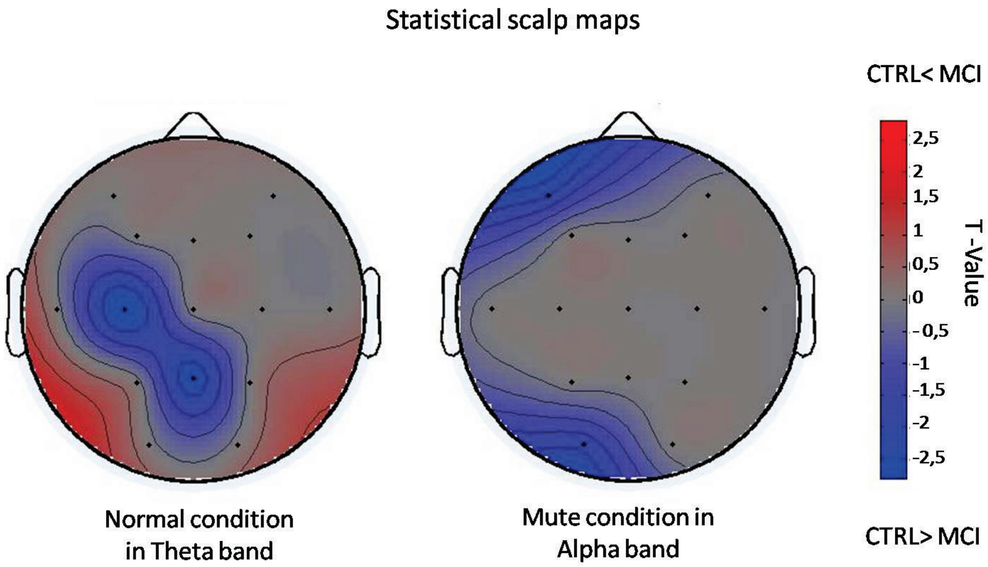


***Figure 1.*** *T-test comparison between subjects considering different conditions, in theta and theta band. Blue color indicates statistically significant enhance of PSD for the healthy child; instead, red color highlights significant increment of electrical activity for the MCI patient. Grey color are used to indicate non-significant values. Colorbar shows the t-values.*

This results are congruent with the ANOVA performed on macro-areas, as shown in Fig. 2. As to the analysis in the theta band, the Area [$F(1,23) = 17.746$, $p=0.000$] and Subject factors [$F(1,23)=7.805$, $p=0.010$] resulted significant. As to the interaction factor Area*Subject, pairwise comparisons revealed significant differences in central ($p=0.036$) and posterior ($p=0.000$) between subjects. As to the contrast performed in the alpha band, the ANOVA returned statistically significant differences for the Area factor [$F(1,23) = 32.541$, $p=0.000$]. As to the interaction factor Area*Subjects, pairwise comparisons revealed a significant difference in the Left side ($p=0.024$) between the two subjects.

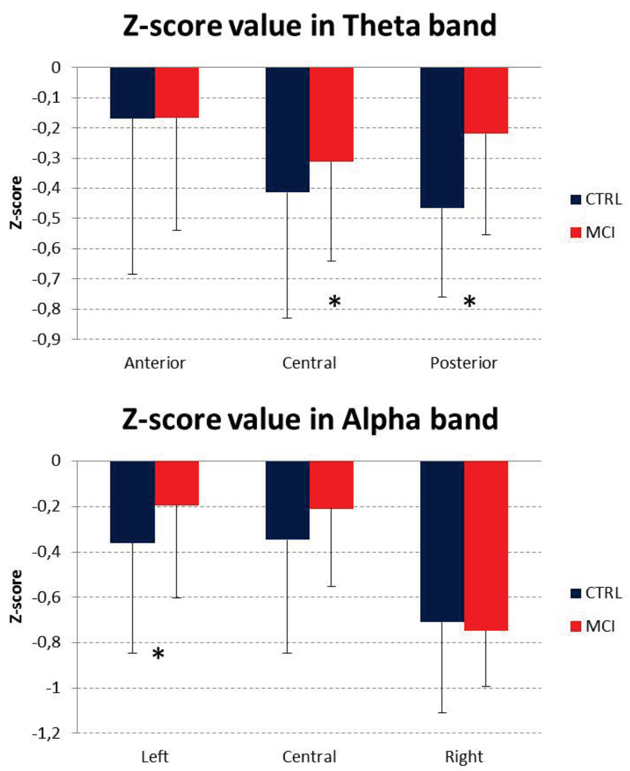

*Figure 2.* *Bar diagram of the Area factor in the theta (up) and alpha Bands (down). Mean and standard deviations are shown for the CTRL (blue) and MCI (red) subject. The asterisks mark statistically significant differences*

### 3.2 Comparison of the logarithmic imbalance index

Fig. 3 shows the average values of the logarithmic imbalance and the percentage of pleasantness for the experimental subjects in the three conditions (NORMAL, DISTORT, MUTE). In the picture we can observe that the MCI subject presents always higher values of the Log IM with respect to the CTRL subject. In particular, this difference is confirmed by the ANOVA test, whose factor Subject resulted statistically significant [$F(1,23) = 24.12$, $p = 0.000$]. We find statistical significance also in all pairwise comparisons of factors Subject*Film for the CTRL subject in the Normal vs Distort condition (Table 1). By computing the difference test on the average percentages of the IM Log we obtained statistically significance for the subjects comparison in the Distort condition ($p=0.0463$).

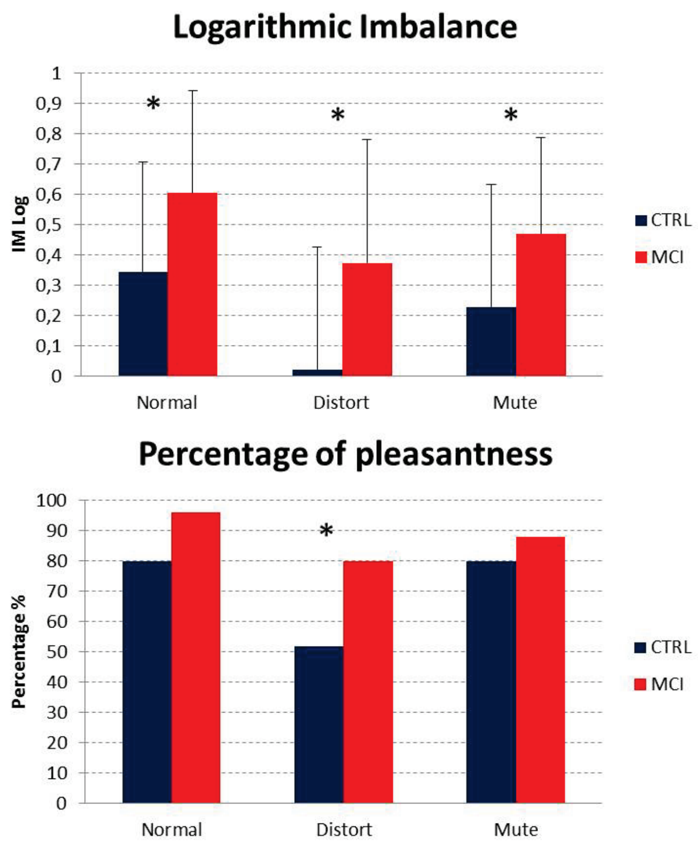


*Figure 3.* *Imbalance index (up) and percentage of pleasantness (down) in the three experimental conditions. The asterisks indicate statistically significant comparisons. Mean and standard deviations are shown. Mean and standard deviations are shown for the CTRL (blue) and MCI (red) subject.*

*Table 1.* *P-values related to the pairwise comparisons of the factor Subject*Film for the comparisons of the Imbalance index.*

| *Subject*Film* | *p-value* |
|---|---|
| Normal (CTRL-MCI) | p = 0,032 |
| Distort (CTRL-MCI) | p = 0,003 |
| Mute (CTRL-MCI) | p = 0,038 |

## 4. Discussion

In the present study, an approach to the estimation of the perceived pleasantness during the fruition of audiovisual stimuli by a healthy child and a cochlear implanted patient has been presented. In particular, we performed a statistical spectral analysis by using an imbalance index and topographic scalp maps. The results of this pilot study suggest that the cochlear implanted patient present a pattern of activation different from the normal hearing subject. The logarithmic imbalance values indicate that the cochlear implanted patient perceives in similar manner the audio in all the three conditions. Instead, the healthy child does not present this phenomena since the Distort condition elicited smaller values of the related cerebral index. As far as concern the statistical scalp maps, we can observe that only the healthy subject shows, in theta band, a tendency to a state of relaxation while listening to the cartoon with normal sound, due at good perception of classical music [Pavlygina et al, 2004]. This does not happen while listening to the cartoon with the distorted sound. In the alpha band, the healthy subject activation patterns could indicate a greater sense of pleasure if compared to the cochlear implanted patient one. These observations are congruent with the analysis of variance performed on scalp areas showing statistical significance in the same areas where an activation in the scalp maps exists.

The significant differences in the EEG activity may be due to the fact that the cochlear implanted patient could differently hear the music with respect to the normal hearing subject. This likely difference in perception of music may not evoke the same emotional states of relaxation and pleasure in patients.

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.

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