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Is the younger the less effortful? An electroencephalographic comparison among consecutive generations of cochlear implant sound processors

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Abstract. Thanks to technological development cochlear implant (CI) recipients have obtained impressive improvement in performances in word in noise recognition tasks. It is worthy to investigate neurophysiological responses underlying these performances, since those are not a sensitive descriptors of the effort experienced by subjects. Listening effort levels, in fact, may change between CI processing conditions for which speech intelligibility remains constant. Aim of the present study was to investigate the EEG patterns relative to Theta activity and Workload index (IWL, the ratio between frontal Theta and parietal Alpha) levels in response to the performing of a word in noise recognition task when employing consecutive generations of CI sound processors (Freedom, CP810, CP910 and Kanso) and using or not the noise reduction filter function. Results suggest that technological development produced a trend of higher levels of processing, as suggested by Theta values obtained in correspondence of the Kanso sound processor use, in particular when the Noise Reduction Filter function was not used. Furthermore, the workload levels, as indexed by the IWL values, were lower when the Noise Reduction Filter function was used. These two considerations support the usefulness of the employment of such EEG estimations for the assessment of clinical devices development.

Keywords: Alpha, Theta, Workload, Word in Noise Recognition, Deafness, Noise Reduction Filter

1. Introduction

Listening effort has been defined as the proportion of limited cognitive resources engaged in interpreting the incoming auditory signal, therefore the presence of noise or distortions in a speech signal would rise the cognitive demand and listening effort [Stenfelt and Rönnberg, 2009]. How listening effort dynamics can be measured by electroencephalographic (EEG) measures is a topic of interest, as reflected by recent studies [for a review Weisz et al., 2011].

Despite impressive improvement in performances obtained by cochlear implant (CI) users in word in noise recognition tasks, thanks to technological development, it is worthy to investigate neurophysiological responses beyond behavioral performances, since those are not a sensitive descriptor of the effort experienced by subjects. Listening effort level, in fact, may change between CI processing conditions for which speech intelligibility remains constant [Pals et al., 2013]. Moreover, it is worthy to study the eventual differences in EEG patterns reported by patients when comparing different CI sound processors, due to their technological differences. In fact, for instance there are evidences that people who upgraded to the CP910 demonstrated an improvement in their understanding of sentences, with individual increases up to 77% [Wolfe et al., 2015].

Since it has been shown that hearing-aid-like noise reduction strategies can improve performances on a secondary task, even when no improvement in speech intelligibility is observed [Sarampalis et al.,

2009], a hearing device feature, such as noise reduction, although maybe not relevant when assessed by an intelligibility test, may instead be beneficial leading to a reduction in listening effort.

The application of neurophysiological measures has been already employed for assisting the clinical evaluation of hearing impaired subjects in CI candidates [Campbell et al., 2011], CI users [Sharma et al., 2015] and tinnitus patients [Cartocci et al., 2012; Attanasio et al., 2013].

Concerning the EEG, two measures have been included in the analysis: the frontal Theta EEG activity [Klimesch et al 1999] and the Workload Index (IWL), defined as the ratio between the activity in the Theta band over the frontal area and the activity in the Alpha band over the parietal area [e.g. Aricò et al 2016a]. Theta activity has been included in the analysis since scientific evidences show increased Theta activity in the frontal cortex in correspondence of enhanced demand of executive control (attention and working memory) [Gevins and Smith, 2003; Jensen et al., 2007; Sterman et al., 1994], the activation of decision-making processes (like resolution of conflicts and error detection) [Beulen, 2011], problem solving demand [Sandkühler and Bhattacharya, 2008], mental workload request [Borghini et al., 2013, 2014; Aricò et al., 2014], and the task complexity are high [Borghini et al., 2017; Aricò et al., 2016b]. Additionally, specifically in relation to the topic of the present paper, higher Theta levels have been identified in correspondence of higher level of listening effort [Wisniewski et al., 2015, 2017].

The mental workload is a complex concept and it involves many cognitive processes, such as stress, attention, time pressure, task difficulty, emotional status, mental effort, physical demand, memory, etc [Borghini et al., 2014]. The IWL cerebral workload levels have been already measured during a forced choice word recognition task in prelingually deaf CI children [Cartocci et al., 2015], and in asymmetric sensorineural hearing loss children (i.e. profound degree on one side, mild-to-severe degree on the other side, and using a hearing aid only in their better ear) [Marsella et al., 2017] with the aim of investigating the EEG patterns in reaction to effortful listening conditions. Both just mentioned studies evidenced higher Theta activity in correspondence of more difficult noise conditions. A previous study on different CI processors comparison including Freedom, CP810 and CP910 showed that CP910 elicited the lowest IWL levels; in addiction the use of the noise reduction filter corresponded to lower IWL values [Cartocci et al., 2016]. Moreover, another study compared the same CI sound processors by a connectivity approach and it showed that the CP910 induced the lower number of inter-connections, among the tested sound processors [Maglione et al., 2017].

Aim of the present study was to investigate the EEG patterns relative to Theta activity and IWL index levels in response to the performing of a word in noise recognition task when employing consecutive generations of CI sound processors and using or not the noise reduction filter function.

2. Material and Methods

2.1. Participants and Protocol

Participants were 14 (42.6±20.8 years old) postlingually deaf unilateral CI users. All patients were not aided in the other ear. The selected disyllabic words for the word in noise recognition task were taken from a clinical standardized set (Audiometria Vocale. Cutugno, Prosser, Turrini) [Turrini et al., 1993]. The task during which the EEG activity was recorded a word in noise recognition task. In particular, stimuli were delivered at an intensity of 65dB HL and the background noise was babble noise, with a signal to noise ratio equal to 10. Stimuli consisted of Italian disyllabic words from "Audiometria Vocale GNResound" [Turrini et al 1993], delivered free-field from a distance of 1 meter from the subject. The signal was delivered frontally and the noise at 180° in relation to the subject's forehead. Each participant was equipped with a 19 channel EEG cap and sitted on a comfortable chair in front of a computer screen. Each trial of the task consisted in the listening of a word, followed by the appearance of four boxes on the screen, each characterized by a different color. On the keyboard, four keys have been customized so to correspond to the different boxes on the screen. Each box reported a disyllabic word, one of them was the target, that is, matched with the just listened word. Participants were asked to press the key button corresponding to the target word. Each target word had the 25% of probability to be placed in each of the four boxes. The task was repeated eight times, one for each processor (Freedom, CP810, CP910 and Kanso) in two conditions: with and without the use of the Noise Reduction Filter. The percentage of correct responses have been evaluated for each condition.

The processors that were considered in the study were all produced by the same company (Cochlear Italia, Bologna, Italy), in the attempt to isolate only the technological improvement:

1. Freedom (2005): it uses one omni-directional microphone and a dual post directional microphone. Both microphone systems help the recipient achieve enhanced directionality in

front of them.

2. CP810 (2009) uses two omni-directional microphones; the output from the second microphone is electronically delayed and subtracted from the first microphone output to provide directionality.
3. CP910 (2013): it presents an improved dual-system microphone in comparison to the CP810, rear and front microphones are calibrated and omnidirectional all the time; it also presents a completely automatic processing of the sounds.
4. Kanso (2016): it presents both left and right microphones calibrated and omnidirectional all the time, and as well as the CP910 the processing of the sound is automatic.

Due to the suggested influence of the background noise on the listening effort of CI recipients [Sarampalis et al., 2009], two filter features conditions were tested:

• No noise filter reduction use, that is the use of ADRO function alone

• Noise filter reduction use, in other words the use of Beam function for the Freedom, of the Zoom function for the CP810 and the SNR-NR function for both the CP910 and Kanso sound processors.

2.2. Electroencephalographic recordings and analysis

A digital ambulatory monitoring system (Bemicro EBNeuro, Italy) was used to record EEG. For the acquisition a 19 channels cap was used. Signals were acquired with a sampling frequency of 256 Hz end collected simultaneously during the experiment. A 50- Hz notch filter was applied to remove the power interference. A ground and a reference electrode were placed on the forehead and the impedances were maintained below 10 (kΩ). The EEG recording was filtered with a band pass filter (2-30 Hz) and then the Independent Component Analysis (ICA) was used to remove artifacts and blink component from the traces [for further technical details see Cartocci et al., 2017]. Successively EEG recordings were segmented into trials. The Power Spectrum Density (PSD) was calculated, observing the EEG PSD values in Theta (4-8 Hz) and Alpha (8-12 Hz) bands. The workload index (IWL) was defined as the ratio between the EEG PSD in Theta band over the central frontal area (F7,F8,F3,F4,Fz) and the EEG PSD in alpha band over the central parietal area (P7,P8,P3,P4,Pz) (1) [Maglione et al 2014].

$$IWL = PSD(\theta F) / PSD(\alpha P) \quad (1)$$

2.3. Statistical Analysis

Repeated measures ANOVA has been performed on EEG data, considering the factor processor (with four levels: Freedom, CP810, CP910 and Kanso) and the factor Noise Reduction Filter (with two levels: Filter and No Filter). Duncan post-hoc has been performed on significant effects and interactions.

3. Results

3.1. Behavioral results

In all the experimental conditions the behavioral performances were clearly above the chance level (Fig. 1 dotted line), and the percentage of correct responses was higher in correspondence of the Kanso processor use, both with and without the noise reduction filter employment in comparison to the other processors (Fig. 1).

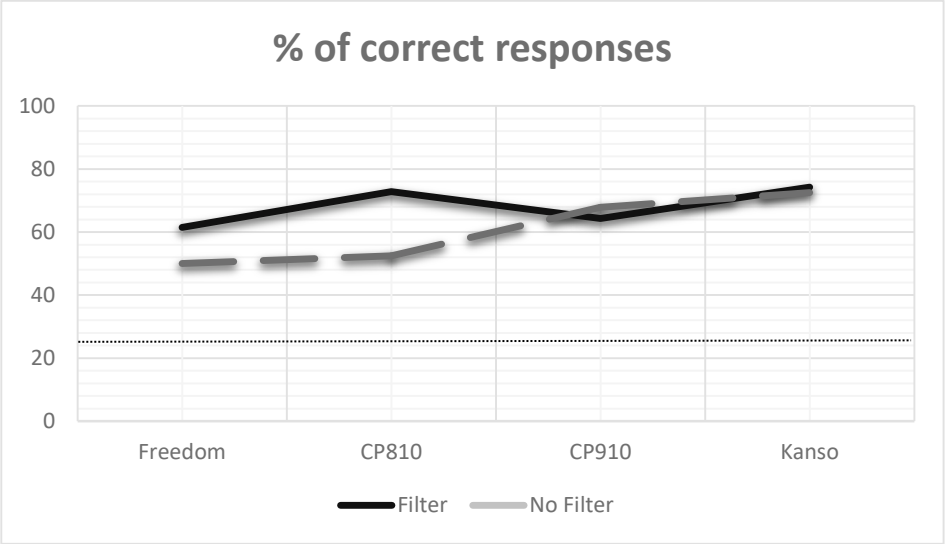

Figure 1. *Percentage of correct responses expressed by the participants during a word in noise recognition task, using four different processors (Freedom, CP810, CP910 and Kanso), under the use or not of the noise reduction filter. The dotted line represents the chance level.*

3.2. EEG results

Results concerning the Theta activity evidenced an increase of the activity in correspondence of the condition with the use of the noise reduction filter, in comparison to not using it ($F(1,13)=5.527$ $p=0.035$). In addition, there was a statistical significant difference circumscribed to Freedom and CP810 processors between the condition with and without noise reduction filter use ($p=0.021$ and $p=0.005$ respectively) (Fig.2). Interestingly, there was a lack of statistical significant difference between the condition with and without the noise reduction filter use for the CP910 and Kanso processors. This would be explained by the improvement in technology that provided an amelioration of the hearing conditions in the less favorable no noise filter reduction use.

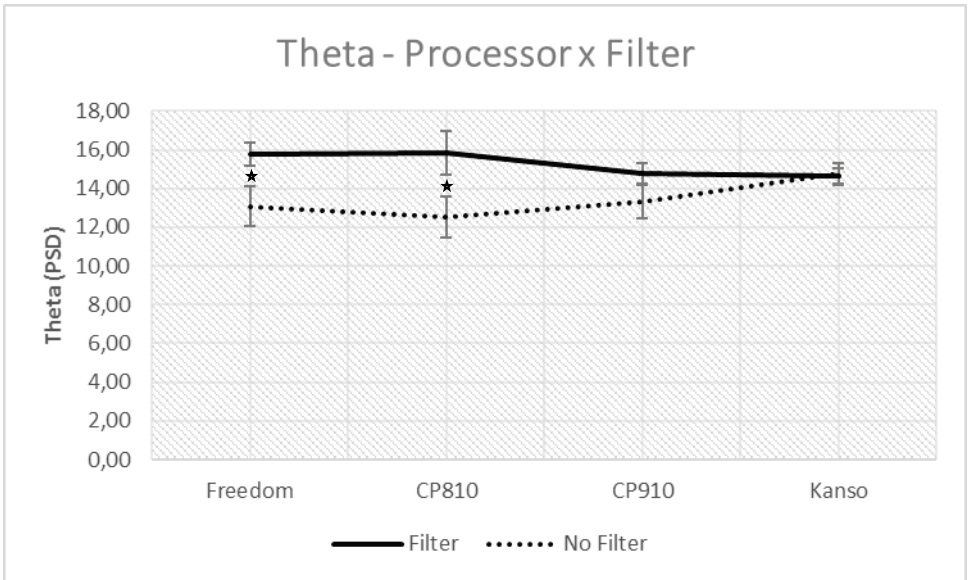

Figure 2. *Theta activity estimated for each tested processors (Freedom, CP810, CP910 and Kanso) in the condition with and without the noise filter reduction use, during a word in noise recognition task. Stars stand for a statistical significance with a p value lower than 0.05.*

The IWL index, reported higher values for the conditions without the use of the noise reduction filter, in comparison to the conditions characterized by the use of such filter indicating an increase in the cognitive workload due to the more demanding experimental condition ($F(1,13)=9.802$ $p=0.008$)

(Fig.3). In fact, the word in noise recognition still constitutes a challenge for hearing impaired persons, despite impressive behavioral performances [Asp et al 2014].

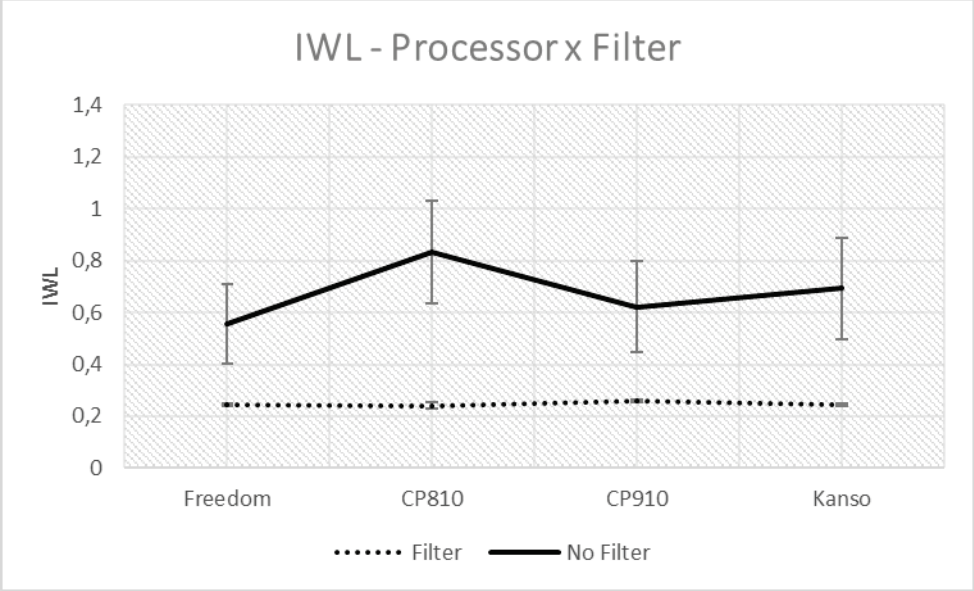

Figure 3. *IWL activity estimated for each tested processors (Freedom, CP810, CP910 and Kanso) in the condition with and without the noise filter reduction use, during a word in noise recognition task.*

4. Discussion

Concerning behavioral results, previous research already evidenced a significant improvement when using Nucleus 6 (CP910) in comparison to Nucleus 5 (CP810) in adults [Mauger et al., 2014] and children, circumscribed at the speech in noise perception test [Plasmans, et al., 2016].

The lack of statistical significant difference between the condition with and without the noise reduction filter use for the CP910 and Kanso processors would be explained by the improvement in technology that provided an amelioration of the hearing conditions in the less favorable no noise filter reduction use. Improved microphones have been in fact introduced in the Kanso in comparison to the CP910 sound processor. The same trend was shared by Theta activity and behavioral performances: a more pronounced difference between the noise reduction filter use or not for the Freedom and CP810 processors, and a lack of difference between these two conditions for the CP910 and Kanso processors. Furthermore, the use of the noise reduction filter corresponded to higher behavioral performances and higher Theta activity. These data could be explained by the increased attention and working memory [Borghini et al 2017; Gevins and Smith 2003; Jensen et al 2007; Sterman et al 1994] in correspondence of the experimental situations that were characterized by the higher percentage of correct responses.

The higher IWL index values reported for the conditions without the use of the noise reduction filter in comparison to the conditions in which the filter was used, according to previous study [Cartocci et al., 2016a,b], would indicate an increase in the cognitive workload due to the more demanding experimental condition, in fact, the word in noise recognition still constitutes a challenge for hearing impaired persons, despite impressive behavioral performances [Asp et al 2014]. Therefore, without the use of the noise reduction filter the presence of the noise would mostly affect the workload levels.

5. Conclusions

Technological development produced a trend of higher levels of processing, as suggested by Theta values obtained in correspondence of the Kanso sound processor use (Fig. 2), in particular when the Noise Reduction Filter function was not used. Furthermore, the workload levels, as indexed by the IWL values, were lower when the Noise Reduction Filter function was used. These two considerations support the usefulness of the employment of such EEG estimations for the assessment of clinical devices development.

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