International Journal of Bioelectromagnetism
Vol. 18, No. 2, pp. 60 - 66, 2016
www.ijbem.org

The influence of different cochlear implant features use on the mental workload index during a word in noise recognition task

Giulia Cartocci[ab*], Anton Giulio Maglione[ab*], Dario Rossi[ab], Enrica Modica[ab], Paolo Malerba[c], Fabio Babiloni[ab]

[a]*Sapienza University of Rome, Rome, Italy*
[b]*BrainSigns srl,Rome, Italy*
[c]*Cochlear srl, Italy*
**These authors equally contributed to the present paper*

Correspondence: G Cartocci, Department of Molecular Medicine, Sapienza University of Rome, viale Regina Elena 291, 00161, Rome, Italy. E-mail: giulia.cartocci@uniroma1.it, phone +39 06 4991 2223

Abstract. The cerebral effort employed during the execution of a task, or even just listening to an audio or watching a video appears as a fundamental insight beyond the personal reported perception and behavioral performance expressed by individuals, both often showing a scarce sensibility. In this context, the mental workload index (frontal EEG increase in the theta band and parietal EEG decrease in the alpha band) estimates the effort spent in the attendance of everyday or also highly demanding activities. In this framework, due to the impact on the quality of life of the users, particularly worthy appears the evaluation of clinical devices, such as cochlear implants. This needing result as extremely immediate since, despite technological development, noisy environments still constitute a challenge for the word recognition in hearing impaired individuals. In the present study the comparison of different cochlear implant processors has been performed, evaluating the workload levels induced by the use of each of them. Results show how the more recent cochlear implant processor produced the lower cerebral workload level during a word in noise recognition task. Furthermore, evidences highlight how the noise filter reduction function support the word discrimination in noisy environments, as suggested by reduced workload levels.

Keywords: Theta, Alpha, Cerebral Workload, EEG, Deafness, Word in Noise Recognition

1. Introduction

Facing adverse listening conditions, such as noisy environments, normal hearing population engages the selective processing of a particular sound and the simultaneous filtering out of irrelevant information, as described by the ‘ selective gain ’ mechanism [Kerlin et al., 2010]. In contrast, for individuals with hearing loss, listening (aided or unaided) in noisy conditions is often reported to be considerably taxing [Kramer et al., 2006; Asp et al., 2015; Caldwell and Nittrouer 2013; Wendt et al., 2016]. As also supported by autonomic nervous system variation data, hearing impaired subjects experience increased effort and/or stress during speech recognition in noise in comparison to normal hearing (NH) listeners. The investigation of listening effort and fatigue has used a variety of methodologies including self-report, behavioural, and physiological measures [McGarrigle et al 2014], but a standard definition of listening effort has yet to be agreed upon, although it is frequently defined as ‘ the attention and cognitive resources required to understand speech ’ [Hicks and Tharpe, 2002; Anderson Gosselin and Gagné, 2011; Fraser et al., 2011; Picou et al., 2011]. Among the above mentioned techniques, the electroencephalographic approach is receiving growing interest and it is the methodology selected in the present study.

The cerebral effort, defined as the electroencephalographic (EEG) frontal theta activity in the PFC has already been reported in several studies, where higher values of effort were connected to higher level of task difficulty [Klimesch, 1999]. By now this kind of evaluation have found various and extremely disparate fields of application, such as in neuroaesthetics, in response to auditory literature stimuli [Cartocci et al. 2016a in press]; in avionic [Aricò et al., 2014; Borghini et al., 2015], in human–computer interaction [Gevins and Smith 2003] and in public service announcements advertising perception [Cartocci et al 2016b]. Moreover, the estimation of the EEG frontal theta increase as a measure of effort, has been recently applied also to more clinical environment, testing the reaction to different listening conditions. In particular, evidences reported how frontal midline theta (4 to 7 Hz) power was found to increase as signal to noise ratio (SNR) decreased in a sentence-recognition task [Wisniewski et al., 2015]. A very recent study, using an auditory-oddball paradigm, showed how the increased theta power likely reflects increased utilization of cognitive-control processes relying on frontal cortical networks [Wisniewski et al., 2017]. Furthermore, the mental workload (IWL) defined as the ratio between the EEG power spectral density (PSD) in the theta frequency band (which usually increases with the increase of task demand) over the prefrontal and frontal cortical areas [e.g. Klimesch 1999] and the EEG PSD in alpha band (which usually decreases with the increase of task demand) over the parietal cortical areas [e.g. Maglione et al., 2014; Borghini et al., 2014]. The IWL has been employed in hearing impaired children during a word in noise recognition task, and results showed that it was modulated by the peculiar challenge of different noise conditions [Cartocci et al., 2015]. The same index was estimated also in cochlear implanted (CI) adults in correspondence of the use of different sound processors and filtering conditions [Maglione et al 2016].

Starting from these premises, aim of the present study was to investigate: i) the capability of the IWL to reveal eventual listening effort differences among older and newer cochlear implant sound processors in a word in noise recognition task and ii) to test if the use of a noise filtering could really improve the IWL induced levels during the same task.

2. Material and Methods

The participant was a 43 years old male unilateral CI user, postlingually deaf (probably genetic etiology), implanted at 35 years old in his right side and not aided in his left ear. He was asked to perform a word in noise (babble noise) recognition. The selected words were disyllabic and taken from a clinical standardized set (Audiometria Vocale. Cutugno, Prosser, Turrini). The experimental conditions were: i) no noise, with the subject hearing words stimuli in quiet; ii) background noise with filter reduction use; iii) background noise without filter reduction use. All the auditory experimental conditions were tested using 3 different kind of processors: Freedom, CP810 and CP910 by Cochlear srl. The signal to noise ratio (SNR) was +5 in all the experimental conditions and the intensity for the stimuli delivery was 65dB. The quiet condition was used only to verify the participant's starting level of words comprehension so, reaching the 95% it will not be discussed anymore in the article.

2.1. Cochlear implant features

The processors included in the testing were all produced by the same company (Cochlear Italia, Bologna, Italy), so to maintain the same quality standard in order of evaluating different processor versions developed along less than 10 years:

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. Two of the Freedom's optional functions have been tested in the present work: i) "Beam" allows to focus on the sounds coming from the direction in which the subject is looking, using a dynamic directionality (e.g. when talking with someone in a crowd); ii) "ADRO" is the normal default directionality response.
2. CP810 (2009): presenting speech processing programs with optional functions, among which ADRO (as Freedom) and "Zoom", both tested in the present study. Zoom provides fixed directionality in front of the subject. CP810 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, and a completely automatic processing of the sounds. Also CP910 ADRO function has been tested, along as the "Background Noise Reduction" (SNR-NR). The SNR-NR works by statistically analyzing the incoming signal (irrespective of direction) and estimating the instantaneous SNR of the sound. It assesses the listening environment and detects the background noise level in each frequency channel. It then estimates the SNR in each channel for each analysis frame. The channels with poor SNRs

indicative of background noise are attenuated, whereas channels with positive SNRs, typically dominated by speech, are retained [Mauger et al., 2012].

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 seen [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. Due to the suggested influence of the background noise on the listening effort of CI recipients, two filters features conditions were tested:

- No noise filter reduction use, that is the use of ADRO alone
- Noise filter reduction use, in other words the use of Beam, Zoom and SNR-NR for the Freedom, CP810 and CP910 respectively.

2.2. Setting of the study

During all the experimental conditions noise and words stimuli were delivered form 1 front and 1 back loudspeakers, positioned 0° and +180° in relation to the subject. In correspondence of the trials including the background noise it was emitted continuously. Each experimental condition comprised 20 trials (20 words), each trial lasted up to 8 seconds, varying in length depending on the subject's response time. During the task the subject listened to a word and then was instructed to verbally say only the just heard word.

2.3. EEG acquisition and analysis

Subject was sitting on a comfortable chair in a shielded room. A digital ambulatory monitoring system (Bemicro EBNeuro, Italy) was used for the EEG recording. For the acquisition a 19 channels cap was used. Electrodes were wet and placed according to the international 10-20 system (Fp1,Fp2, F7,F8,F3,F4,Fz,T3,T4,C3,C4,Cz,P7,P8,P3,P4,Pz,O1,O2). 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 manually remove artifacts and blink component from the traces by an experienced researcher. Successively EEG recordings were segmented into epochs of 1 second each, shifted of 0.25 seconds. The Power Spectrum Density (PSD) was calculated for each epoch and channels, observing the EEG PSD values in theta (4-8 Hz) and alpha (8-12 Hz) bands. The index of workload (IWL, Formula 1) was defined as the ratio between the averaged EEG PSD in theta band over the central frontal area (Fz) and the average value of EEG PSD in alpha band over the central parietal area (Pz) [Klimesch, 1999].

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

The IWL values were analyzed by the Analysis of Variance (ANOVA) in order to compare the different: kinds of processor (Freedom, CP810 and CP910) and the different noise filter conditions of the devices (No noise filter reduction and Noise filter reduction) during the task.

3. Results

3.1. Behavioral word recognition performances

Behavioral results were based on the number of words correctly identified within each trial by the subject. Even without reporting a statistical significance (ANOVA $F(5,95)=1.34$ $p=0.25$) a higher percentage of correct responses was obtained in the Noise filter reduction application in comparison to the No noise filter reduction condition. In particular, the best score was obtained for both the Noise filter reduction and the No noise filter reduction during the CP910 sound processor use.

3.2. EEG results

The comparison between the IWL values obtained during the testing of the three different kinds of sound processor (Freedom, CP810 and CP910) showed a statistical significant difference ($F(2,172)=3.56$ $p=0.03$), with the lower value reported in the CP910 trial and the higher value in the

Freedom trial (Fig.1). The post-hoc analysis performed on this effect highlighted statistically significant higher IWL values for the Freedom in comparison to the CP910 processor (p=0.01).

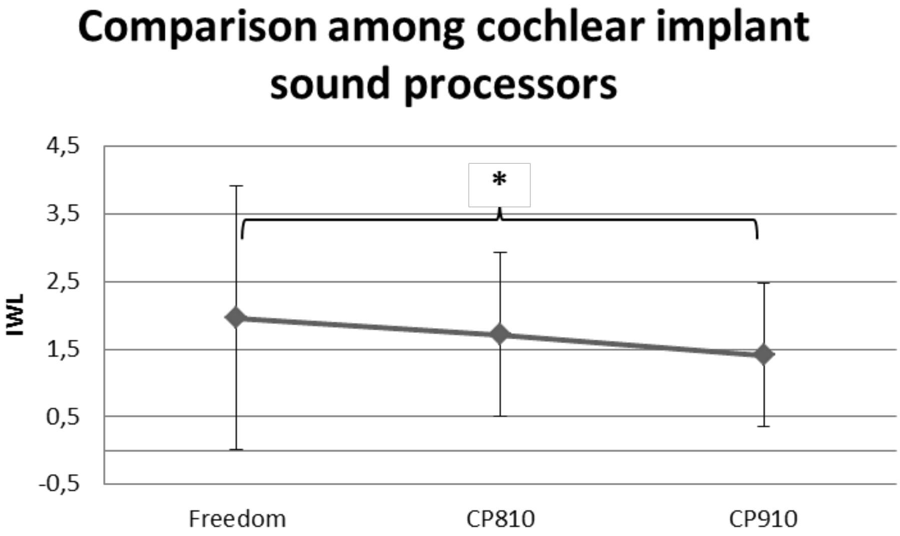

Figure 1. *In the figure are represented the IWL levels estimated for the three cochlear implant sound processors investigated (Freedom, CP810 and CP910). ANOVA analysis showed a statistical significant difference among the processors (p=0.03) and a statistically significant increase of the IWL reported for the Freedom use in comparison to the CP910 use (p=0.01).*

Furthermore, considering the filters features (Fig.2), the trials in which the Noise filter reduction function was adopted reported statistically significantly lower IWL values in comparison to the trials with No noise filter reduction use ($F(1,87) = 4.09$ $p = 0.05$).

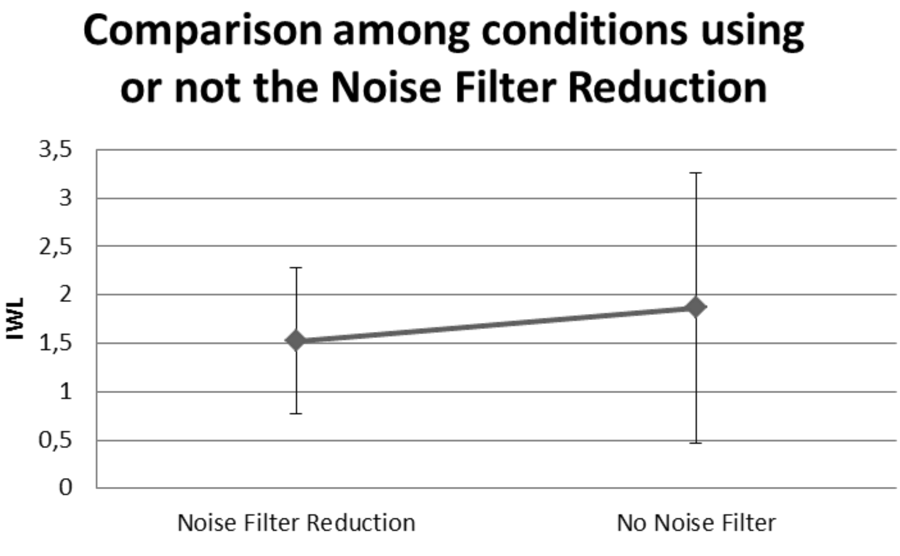

Figure 2. *In the figure are represented the IWL levels estimated for the conditions using or not the cochlear implant Noise Filter Reduction function. ANOVA analysis showed a statistical significant difference among the conditions (p=0.05).*

4. Discussion

The sound processors included in the present study have been already compared in literature on the basis of traditional clinical outcomes: such as speech perception tests. Data showed a significant improvement when using Nucleus 6 (CP910) in comparison to Nucleus 5 (CP810) in adults [Mauger et al., 2014] and children, but circumscribed at the speech in noise perception test [Plasmans, et al., 2016]. Nevertheless, since the evidence that listening effort may change between cochlear implant (CI) processing conditions for which speech intelligibility remains constant [Pals et al 2013], the neurometric approach to the listening effort in CI users appears as a useful instrument to get neurophysiological and sensitive insights. It has been approached by EEG studies using event related potentials (ERP), reporting a correlation between N2/N4 latencies and rated listening effort [Finke, et al., 2016]. Furthermore, beyond the rating of the effort level, a previous study on hearing impaired children showed an increase of IWL values in correspondence of the most demanding noise condition for the participants [Cartocci et al., 2015]. Differently from this study, the present results focus on the device-related listening effort matter instead of environment-related listening effort. With regards to the IWL values obtained by the experimental subject while adopting each of the different sound processors, during the use of the CP910 were estimated the lower IWL levels. The present results are in accord to a very recent study investigating the IWL induced by an auditory forced choice word recognition task in adult unilateral cochlear implant users [Maglione et al. 2016]. In accord to the present work, where the use of the noise filtering reduction produced the lower IWL values, those authors found evidence of a statistical significance of the interaction between kinds of processors and noise filter reduction use, with a trend of lower IWL values in correspondence of the use of the CP910 processors. Some authors hypothesize that Noise Reduction (NR) features in hearing devices reduce listening effort and frees up cognitive resources for other tasks [Sarampalis et al., 2009]. Hafter and Schlauch [1992] proposed that NR algorithms in the processor do not improve speech reception thresholds (SRTs) because performing a function similar to that of the listeners' auditory and cognitive systems. However the same authors suggested that the NR, substituting these physiological functions, may lighten listeners' cognitive load. Therefore, NR might not affect the SRT but may release attentional resources to be used for other, simultaneous tasks. This reduction in cognitive load could be important in natural settings, where multitasking is the norm and cognitive demands are greater. The concept of identifying devices allowing to save cognitive resources appears extremely worthy for facing everyday challenging situations such as noisy environments for cochlear implanted subjects. This observation acquires clear evidence just thinking for example at the requirements for the sustained attention that children have to generate during their learning processes in the early scholar period of their life. Preschoolers and school-aged children with CI present 2 to 5 times greater risk of clinically significant deficits in comparison to NH children, for instance in the areas of comprehension and conceptual learning and attention [Kronenberger, et al., 2014].

Finally, despite the obvious limitation of the single case nature of the present study, data suggest the applicability and sensitivity of mental workload estimation for the evaluation of the most proper biomedical device and features under different environmental conditions in patients. This could help facing the issue that, although behavioural performances (e.g. speech intelligibility task and the NASA TLX) [Pals et al., 2013] and self-report measures remain an important factor in deciding clinical significance, several inconsistencies among apparently related studies [McGarrigle et al., 2014] support the employment of neurometric measures to deepen the understanding of the listening effort processes.

References

Anderson Gosselin P, Gagné J-P. Older adults expend more listening effort than young adults recognizing speech in noise. *J Speech Lang Hear Res*. 54(3):944–58,2011.

Aricò P. *et al.* Towards a multimodal bioelectrical framework for the online mental workload evaluation. in *2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society* 3001–3004, 2014.

Asp F, Mäki-Torkko E, Karltorp E, Harder H, Hergils L, Eskilsson G, Stenfelt S. A longitudinal study of the bilateral benefit in children with bilateral cochlear implants. *Int J Audiol*, 54(2): 77-88, 2015.

Borghini G, Aricò P, Di Flumeri G, Salinari S, Colosimo A, Bonelli S, Napoletano L, Ferreira A, Babiloni F. Avionic technology testing by using a cognitive neurometric index: A study with professional helicopter pilots, in *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 6182–6185,2015.

G. Borghini, L. Astolfi, G. Vecchiato, D. Mattia and F. Babiloni, "Measuring neurophysiological signals in aircraft pilots and car drivers for the assessment of mental workload, fatigue and drowsiness," *Neurosci Biobehav Rev*, vol. 44, pp. 58-75, Jul 2014.

Caldwell A, Nittrouer S. Speech Perception in Noise by Children With Cochlear Implants. *J Speech Lang Hear Res*, 56(1), 2013.

Cartocci G, Maglione AG, Modica E, Rossi D, Canettieri P, Combi M, Rea R, Gatti L, Perrotta CS, Babiloni F, Verdirosa R, Bernaudo R, Lerose E, Babiloni F. The "NeuroDante project": neurometric measurements of participant's reaction to literary auditory stimuli from Dante's "Divina Commedia". *Symbiotic*, 2016a in press.

Cartocci G, Modica E, Rossi D, Maglione AG, Venuti I, Rossi G, Corsi E, Babiloni F. Against smoking public service announcements, a neurometric evaluation of effectiveness. in *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC),* 2016b. In press

Cartocci G, Maglione AG, Vecchiato G, Di Flumeri G, Colosimo A, Scorpecci A, Marsella P, Giannantonio S, Malerba P, Borghini G, Aricò P, Babiloni F. Mental workload estimations in unilateral deafened children, in *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 1654–1657, 2015.

Finke M, Büchner A, Ruigendijk E, Meyer M, Sandmann P. On the relationship between auditory cognition and speech intelligibility in cochlear implant users: An ERP study. Neuropsychologia. 2016 Jul 1;87:169–81.

Fraser S, Gagné J-P , Alepins M, Dubois P . . Evaluating the effort expended to understand speech in noise using a dual-task paradigm: The effects of providing visual speech cues *.J Speech Lang Hear Res* , 53 , 18 – 33, 2011.

Gevins A, Smith ME. Neurophysiological measures of cognitive workload during human-computer interaction. *Theoretical Issues in Ergonomics Science* **4,** 113–131,2003.

Hafter ER and Schlauch. Cognitive factors and selection of auditory listening bands. *Noise-induced hearing loss* (pp. 303–310). Philadelphia: B.C. Decker, 1992.

Hicks CB, Tharpe AM. Listening effort and fatigue in school-age children with and without hearing loss *.J Speech Lang Hear Res* , 45 , 573 – 584, 2002.

Kerlin JR, Shahin AJ, Miller LM. Attentional gain control of ongoing cortical speech representations in a " cocktail party ". *J Neurosci*, 30 , 620 – 628, 2010.

Klimesch W. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research Reviews*. 29(2–3):169–95,1999.

Kramer SE, Kapteyn TS, Houtgast T . Occupational performance: Comparing normally-hearing and hearing-impaired employees using the Amsterdam checklist for hearing and work *.Int J Audiol* , 45 ,503 – 512, 2006.

W.G. Kronenberger, et al. Neurocognitive risk in children with cochlear implants. *JAMA Otolaryngol Head Neck Surg*, 140(7): 608-15,2014.

A. Maglione, G. Borghini, P. Aricò, F. Borgia, I. Graziani, A. Colosimo, W. Kong, G. Vecchiato and F. Babiloni, "Evaluation of the workload and drowsiness during car driving by using high resolution EEG activity and neurophysiologic indices," *Conf Proc IEEE Eng Med Biol Soc*, pp. 6238-41 , 2014.

Maglione AG, Cartocci G et al. Cochlear implant features and listening effort induction: measurement of the mental workload experienced during a word in noise recognition task. *Front. Hum. Neurosci.* Conference Abstract: SAN2016 Meeting. doi: 10.3389/conf.fnhum.2016.220.00043

Mauger SJ, Arora K, Dawson PW. Cochlear implant optimized noise reduction. J Neural Eng. 2012 Dec;9(6):65007.

Mauger SJ, Warren CD, Knight MR, Goorevich M, Nel E. Clinical evaluation of the Nucleus® 6 cochlear implant system: Performance improvements with SmartSound iQ. Int J Audiol. 2014 Aug;53(8):564–76.

McGarrigle R, Munro KJ, Dawes P, Stewart AJ, Moore DR, Barry JG, et al. Listening effort and fatigue: What exactly are we measuring? A British Society of Audiology Cognition in Hearing Special Interest Group "white paper." *International Journal of Audiology*, 53(7):433–45,2014.

Pals C, Sarampalis A, Baskent D. Listening effort with cochlear implant simulations. *J Speech Lang Hear Res*. 56(4):1075–84,2013.

Picou EM, Ricketts TA, Hornsby BWY. Visual cues and listening effort: Individual variability. *J Speech Lang Hear Res,* 54 ,1416 – 1430, 2011.

Plasmans A, Rushbrooke E, Moran M, Spence C, Theuwis L, Zarowski A, et al. A multicentre clinical evaluation of paediatric cochlear implant users upgrading to the Nucleus® 6 system. International Journal of Pediatric Otorhinolaryngology. 2016 Apr 1;83:193–9.

Sarampalis A, Kalluri S, Edwards B, Hafter E. Objective measures of listening effort: effects of background noise and noise reduction. J Speech Lang Hear Res. 52(5):1230–40, 2009.

Wendt D, Dau T, Hjortkjær J. Impact of Background Noise and Sentence Complexity on Processing Demands during Sentence Comprehension. *Front Psychol*, 7, 2016.

Wisniewski MG, Thompson ER, Iyer N, Estepp JR, Goder-Reiser MN, Sullivan SC. Frontal midline θ power as an index of listening effort. *Neuroreport*. 26(2):94–9, 2015.

Wisniewski MG. Indices of Effortful Listening Can Be Mined from Existing Electroencephalographic Data. *Ear Hear*. 38(1):e69–73, 2017.