Bioengineering for Communication Disorders

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Abstract—This paper resumes the main research activities and results obtained at the CNR Institute of Biomedical Engineering in the field of communication disorders. Main research challenges are focused on the design, development and use innovative technologies and methods for: i) early and objective detection of hearing loss in newborns and adults; ii) enhancement of fitting and stimulation in neuro-prostheses; iii) screening for hearing ability in adults and the elderly.

I. INTRODUCTION

Hearing impairment continues to be one of the most prevalent and chronic disability, affecting over 270 million people in the world. One quarter of hearing impairment begin during childhood. Consequences of hearing impairment include inability to interpret speech sounds, often producing a reduced ability to communicate, delay in language acquisition, economic and educational disadvantage, social isolation and stigmatization.

II. CHALLENGE #1 – OBJECTIVE IDENTIFICATION OF HEARING LOSS

Detecting and responding to hearing impairment in babies and young children is vital for the development of speech and language. Thus, one of the current challenges in the field of the communication disorders is the development of methods and techniques for objective and early identification of hearing impairment in newborns, children and, more generally, adults.

Otoacoustic emissions (OAEs) (see the example in Fig.1) are fast, accurate, objective, non-invasive tests for the assessment of hearing functionality in newborns and adults.

In 2000, IsIB CNR promoted and coordinated the EU Project AHEAD II Advancement of Hearing Assessment Devices-Immediate Intervention, conceived to establish and coordinate a network of research centers and hospitals, manufacturers, scientific societies and international organizations to advance the whole field of OAEs with particular emphasis to universal newborn hearing screening programmes.

One of the most widespread and reliable techniques for the extraction of objective parameters of clinical value from OAEs is the Wavelet Transform (WT) (Tognola et al., 1998). The WT has been used, for example, to study the functionality of cochlear active mechanisms in normal hearing subjects affected by Williams syndrome (see Fig. 2). The analysis of energy and latency of OAE frequency components revealed that children with Williams syndrome have significantly lower OAE energy compared to the control group, demonstrating a sub-clinical dysfunction of the inner ear in subjects with otherwise normal hearing (Paglialonga et al., 2010).

Fig. 1. Otoacoustic emissions recording: a) probe for otoacoustic emissions measurement; b) example of an otoacoustic emission recorded in a normal hearing child.

Fig. 2. Mean energy of OAE frequency components measured in the control (diamonds) and in the Williams group (squares). Filled black marks indicate the frequency components where the differences in mean energy between the two groups were significant (p <0.05).
The WT was also used to monitor and evaluate cochlear maturation in preterm neonates: the latency of OAE frequency components, which is a quantitative descriptor related to cochlear maturation, progressively decreases toward physiological value from 28 wks to 40 wks post-conception, as shown in Fig. 3 (Tognola et al., 2005).

![Fig. 3. Mean latency of OAE frequency components measured in premature neonates (lines with symbols) and full-term newborns (bold line). Data from premature newborns are divided into groups according to the post-conception age.](image)

The WT was also recently used to monitor possible subtle cochlear modifications in subjects exposed to electromagnetic fields from mobile phones, showing no measurable effects on the cochlear active mechanisms of human subjects immediately after a 10 min exposure at the maximum power of a GSM mobile phone (Paglialonga et al., 2007).

III. CHALLENGE #2 – OPTIMAL FITTING OF HEARING PROSTHESSES

Properly fitted hearing prosthesis can improve communication in over 90% of people with even severe-to-profound hearing impairment. Technological advances in integrated circuitry and microchips have made feasible the development of extremely miniaturized hearing prosthesis with excellent sound enhancement and fidelity. The key point to success in making people otherwise profoundly deaf to hear again is not only the availability of high-tech hearing instruments; it is important, also, to go deeper in the knowledge of the mechanisms of interactions between the stimulating electromagnetic fields of the hearing prosthesis and the excitable structures of the hearing system. This knowledge is necessary to achieve optimal stimulation patterns and better hearing aid performances.

Research challenges in the field of cochlear implants include, for example, the definition and optimization of speech processing algorithms for real-time application, and their adaptation to the ‘non-ideal’ operating conditions typical of cochlear implants, such as the limited number of stimulation channels and the limited electrical stimulation rate. Algorithms based on the Discrete Wavelet Transform (DWT) were developed and optimized to minimize redundancy of speech coding and adapt to the non-stationary character of speech (Paglialonga et al., 2007).

The optimization of electrical stimulation strategies in cochlear implants is also an important research issue. Three-dimensional models that combine anatomical representations of the cochlear structures and the electrical properties of cochlear tissues allow to compare the different stimulation strategies and optimize parameters and settings. Fig. 4a shows the optimization of the neural excitation field of a cochlear implant in a model of a human cochlea (the green shape in the figure). Following results of numerical approaches, the optimized stimulation strategies could be implemented on a real cochlear implant so that the excitation field was experimentally verified (see Fig. 4b).

![Fig. 4. Optimization of the neural excitation field of a cochlear implant: a) numerical simulations on a three-dimensional cochlear model; b) experimental measurements of electric potential and current density distributions.](image)

Experimental measurements of speech understanding in cochlear implant recipients revealed that the optimized excitation field produced a significant increase in speech understanding performance (Tognola et al., 2007)
IV. CHALLENGE #3 – ADULT HEARING SCREENING

In the EU, 28% of the population will be over 60 years old by 2020. In high-income countries, 18.5 millions of people aged 60 years and over experienced moderate to severe hearing loss whereas in low- and middle-income countries the number of people aged 60 years and over suffering from hearing loss is further increased to 43.9 millions. Despite the prevalence and burden of hearing disabilities, they are still largely underdetected and underdiagnosed in older adults. For screening for hearing disabilities to become the rule rather than the exception, novel strategies should be explored to make screening a feasible part of routine care. In this framework, IsiB CNR is coordinating the EU Project “AHEAD III” Assessment of Hearing in the Elderly: Aging and Degeneration, Integration through Immediate Intervention (FP7, 2008-2011) to provide evidence of the effects of hearing impairment in adults and particularly in the elderly, increase the awareness about early detection and intervention for hearing impairment in adults and particularly in the elderly, and analyze costs and minimum requirements associated with the implementation of large scale programmes of hearing screening and intervention in the elderly.

A new test, the Speech Understanding in Noise (SUN) test, has been developed to screen adults and elderly for hearing ability (Grandori et al., 2010). The SUN test is based on the recognition of a set of vowel-consonant-vowel stimuli in background noise, presented in a three-alternatives forced-choice paradigm by means of a touch-screen interface (Fig. 5a).

![Fig. 5. The Speech Understanding in Noise (SUN) test: a) Screenshot of the touch-screen interface used in the SUN test; b) outcomes of the SUN test in the tested population (1200 subjects). The tested ears were divided into three classes according to their pure-tone audiometry (PTA). PTA worsens from class I to class III. SUN test outcomes were divided into three categories, normal hearing ability (score \( \geq 9 \)), slightly impaired hearing ability (score 7 or 8), and impaired hearing ability (score \(< 6\)).](image)

The test is quick (less than 1 minute per ear) and fully automated. The SUN test was offered to more than 1200 subjects aged 55-90 yrs and proved to be reliable in detecting hearing impairment in adults and older adults (Fig. 5b). Test scores were stable with increasing age, provided that the differences in hearing sensitivity were taken into account, indicating that the cognitive load associated with the speech recognition task was limited and did not influence test outcomes in the older age groups. Comparison of the SUN test performance observed in low- and in high- noise environments provided evidence that the test is robust to background noise and, thus, feasible for use in hearing screening in non clinical settings.

ACKNOWLEDGMENTS


REFERENCES