Institution: University of Essex

Unit of Assessment: 4 – Psychology, Psychiatry and Neuroscience

Title of case study: BioAid: The development and uptake of a hearing aid mobile app

1. Summary of the impact

Developed at Essex, the ‘BioAid’ app transforms iPhones and iPods into fully functional hearing aids. The app provides readily-available and cost effective access to hearing aid technology, allowing users to test its settings at their own pace in their everyday environments. BioAid is the culmination of a research programme that has systematically built computational simulations of different types of hearing loss and developed biologically-realistic algorithms to compensate for these impairments. Launched as an open-source app in December 2012, by 31st July 2013 it had been downloaded by more than 20,000 users in over 90 countries. Over various periods in that time, BioAid has also been *iTunes’* most downloaded medical app in 11 countries.

2. Underpinning research

Under the direction of Ray Meddis (Emeritus Professor), BioAid’s underpinning research was conducted at the Hearing Research Laboratory at Essex. Over a 30-year period Meddis has been at the forefront of research encompassing human auditory modelling, measurement of hearing and impairment, and the development of hearing aid technology. He has developed computer models that simulate the underlying physiological processes in the auditory periphery and built them into composite systems that combine individual components of hearing. This approach enables the understanding of the unique function of each component, as well as how it contributes to the auditory periphery as a whole. As far as we are aware, no alternative computational system with equivalent functionality has been developed to the same level.

The Dual Resonance Non-Linear (DRNL) filter model that Meddis published in 2001 (Meddis, O’Mard and Lopez-Poveda, 2001) is an example of an individual component of hearing that has been used for simulations (Lopez-Poveda, Plack and Meddis, 2003). Along with other models, it has been used to improve understanding of the *non-linear* characteristic of hearing (Lopez-Poveda, Plack and Meddis, 2003; Meddis and O’Mard, 2005). Non-linearity is a crucial aspect of auditory processing; sounds heard on a day-to-day basis may range typically by 100dB, yet when processed by the human ear they are compressed. The DRNL filter provides a biologically realistic approach to audio processing that is directly applicable to the field of hearing aid development.

A number of key research outcomes were drawn together and further extended during the milestone ‘Hearing Dummy’ research programme, funded by EPSRC in 2007, with Swiss hearing aid manufacturer Phonak as an industrial partner. The research team at Essex included Research Fellows Nick Clark, Wendy Lecluyse and Tim Jürgens. The programme targeted improvement in the process and accessibility of hearing assessment and subsequent hearing aid dispensation. It followed a biological approach to the investigation of sensorineural hearing impairment and used a computer model of the auditory periphery. To reflect a human’s ability to hear sound at different frequencies (or pitches), this model incorporated multiple channels, which could be adapted to represent the specific pathology of an individual patient. This would result in an individualised model that could be used in the same way as a tailor’s ‘dummy’, to enable objective patient evaluation and subsequent hearing aid optimisation (Meddis, 2006; Meddis and O'Mard, 2006).

The researchers initially used ‘Hearing Dummies’ to simulate various auditory impairments and to build computational models that could compensate for them. In ‘tailoring’ the hearing dummy, the first stage involved the development of three tests of the psychophysical symptoms behind a patient’s condition, designed specifically for rapid clinical application. Their use also yielded individualised patient auditory profiles showing far greater variation in hearing pathology than would be expected from audiogram alone. Based on the results of these tests, the auditory periphery model could be modified to render an accurate representation of patients’ hearing. If the model’s performance matched that of the patient, it could be considered an accurate hearing dummy, and could subsequently be used to gain an enhanced understanding of the hearing impairment, without requiring the patient to be present (Lecluyse and Meddis, 2009).

Using the hearing dummy, a biologically-based algorithm could be modified to apply gain across specifically targeted frequencies, restoring those hearing functions diagnosed as being lost. The algorithm incorporated instantaneous compression, to protect the user from sudden loud sounds, along with filtering to reduce associated distortions. The fully customised algorithm is represented as a multi-channel system, where the parameters of each channel can be adjusted separately, realising an effective, operational hearing aid (Meddis and Lecluyse, 2011; Clark et al., 2012; Lecluyse et al., 2013).

3. References to the research

Meddis, R., L.P. O'Mard and E.A. Lopez-Poveda (2001) A computational algorithm for computing non-linear auditory frequency selectivity. *Journal of the Acoustical Society of America*, 109, 2852-2861. DOI:10.1121/1.1416197

Lopez-Poveda, E.A., C.J. Plack and R. Meddis (2003) Cochlear nonlinearity between 500 and 8000 Hz in listeners with normal hearing. *Journal of the Acoustical Society of America*, 113, 951-960. DOI:10.1121/1.1534838

Meddis, R. and L.P. O'Mard (2005) A computer model of the auditory nerve response to forward-masking stimuli. *Journal of the Acoustical Society of America*, 117, 3787-3798. DOI:10.1121/1.1893426

Meddis, R. (2006) Auditory-nerve first-spike latency and auditory absolute threshold: a computer model. *Journal of the Acoustical Society of America*, 119, 406-417. DOI:10.1121/1.2799914

Meddis, R. and L.P. O'Mard (2006) Virtual pitch in a computational physiological model. *Journal of the Acoustical Society of America*, 120, 3861-3896. DOI:10.1121/1.2372595

Lecluyse, W. and R. Meddis (2009) A simple single-interval adaptive procedure for estimating thresholds in normal and impaired listeners. *Journal of the Acoustical Society of America*, 126, 2570-2579. DOI:10.1121/1.3238248

Meddis, R. and W. Lecluyse (2011) The psychophysics of absolute threshold and signal duration: A probabilistic approach. *Journal of the Acoustical Society of America*, 129, 3153-3165. DOI:10.1121/1.3569712

Clark, N.R., G. Brown, T. Jürgens and R. Meddis (2012) A frequency-selective feedback model of auditory efferent suppression and its implications for the recognition of speech in noise. *Journal of the Acoustical Society of America*, 132(3), 1535-1541. DOI:10.1121/1.4742745

Lecluyse, W., C.M. Tan, D. McFerran and R. Meddis (2013) Acquisition of auditory profiles for good and impaired hearing. *International Journal of Audiology*, 52, 596-605. DOI:0.3109/14992027.2013.796530

Research funding:

Meddis, *A biologically-inspired hearing aid*, EPSRC, Aug '10 – Apr '12, £134,420
Meddis, *Hearing Dummy*, EPSRC, Sep '07 – Feb '11, £357,790
Meddis, *Tinnitus and Hearing Deficits*, RNID, Oct '08 – Sep '10, £69,642
Meddis, *A computer model of pitch processing in the auditory brainstem*, BBSRC, Apr '03 – Mar '06, £227,932
Meddis, *Human Auditory Localisation*, British Aerospace, Jan '99 – Dec '01, £37,800
Meddis, Winter, *Neuronal correlates of across-frequency processing in the auditory system*, Wellcome Trust, Aug '98 – Jul '01, £105,556
Meddis, *Low-level Signal Processing in the Auditory Brainstem*, Sep '96 – Jan '97, £20,040

4. Details of the impact

From Research to Impact: Two significant factors currently limit use of hearing aids: cost and availability. WHO figures (2013) indicate that worldwide 360 million people have a disabling hearing loss, including 30% of those over 65, especially in Asia and sub-Saharan Africa. Hearing loss affects functional communication, language development in children, academic achievement, social and emotional communication and employment opportunities, with knock-on effects on wider economies. Despite clear demand, current production of hearing aid technology meets less than 10% of global need and in developing countries fewer than 1 in 40 people who need a hearing aid have one. The annual cost of hearing impairment in the EU is estimated to be €224 billion and, whilst in the developed world hearing tests and effective hearing aids are expensive, in much of the third world they are unobtainable. To address these challenges the group used further EPSRC funding to develop BioAid, a smartphone app that transforms an iPhone or iPod into a fully functioning hearing aid. The BioAid app was developed to provide a freely available device that could be used worldwide not only by individuals, but also as a hearing test application that can be used by 'micro-entrepreneurs', equipped with a mobile device and some other basic equipment, enabling them to cost-effectively assess the hearing of those in remote regions that currently lack any provision for hearing impairment.

The BioAid app: BioAid used the computational models from the Hearing Dummy projects to derive correctional strategies to restore lost hearing functions. These correctional strategies form the basis of six basic audiogram shapes, divided into a total of twenty-four profiles (see figure 1). With a standard pair of headphones, users are able to test these settings at their own pace and in their everyday environments, in order to find which one best suits their needs. An extensive explanation of the research and technology behind BioAid, as well as the app's features and capabilities, is available on the BioAid website [see corroborating source 1].

Fig.1: BioAid offers 6 audiogram profiles, each divided into 4 sub-profiles.

BioAid Dissemination: BioAid was made freely available via the *iTunes* online store in December 2012, and its launch was supported by a project website and Facebook page [1] [2] [3]. In March 2013 the app was showcased in a University press release and vodcast [4] and featured in online magazines across the world including: PhysOrg's 'Medical Xpress', 'medgadget', 'Healthline', 'Hearing Life', 'popbuzz.me' (Australia), and 'Top News' (United Arab Emirates). The vodcast received 4,500 views in the first two months [5]. As awareness grew, the story also received global media coverage. The project website details how it was featured both in a large number of mainstream news outlets, as well as websites covering areas such as healthcare and technology [6]. In June 2013, Meddis gave the invited keynote talk to the 'International Forum for Hearing Instrument Developers' in Oldenburg, Germany (http://hadf.hoertech.de/) where he introduced BioAid to manufacturers. This invitation-only meeting for scientists, engineers, clinicians and managers involved in developing the system technology for hearing instruments hosts key individuals from industry, universities and other research institutions. The 2013 programme included contributions from GN ReSound, Starkey and Widex – three world-leading providers of hearing aid technology.

BioAid Uptake: By making the app freely available to download and use, the research team intended that the widespread proliferation of smartphones in society would ensure a broad audience of beneficiaries could be reached. By August 2013, BioAid had been downloaded by more than 20,000 users in over 90 countries, with the greatest number of downloads occurring in the US, Germany and Japan [7] [8]. By the same date BioAid had also been recognised, over various periods, as the *iTunes* most downloaded medical app in 11 countries, including Germany, Egypt and Bahrain [9]. A not-for-profit company working in central Africa has begun collaboration with the Essex Hearing Lab to develop a cost-effective hearing test package for use in remote areas where lack of resources, power and mobile phone reception limit individual use of the app.

BioAid Feedback: Overwhelmingly positive feedback received on both the project and *iTunes* websites show that BioAid is enabling significant health and social benefits [10]. Users of varying ages and personal circumstances report how BioAid can outperform conventional hearing aids and describe the positive effects that its use is having, ranging from improved social interactions to increased engagement in education. Users also commend BioAid's cost-effectiveness, its ease of use and its impressive range of settings. These figures of merit are acknowledged by an indicative sample of user feedback, below:

> "BioAid enabled me to […] thoroughly enjoy Easter lunch with my family and hear every conversation and domestic sound for the first time in 30 or more years, absolute bliss!"
>
> "[BioAid] is so much more helpful than anything else I have experienced"
>
> "Its a great substitute or even better than the hearing aids sold in market for thousands of pounds"
>
> "Since downloading the BioAid app on his iPad and iPod, my son is actively taking part in class discussions"
>
> "[BioAid] provides a simple user friendly way of selecting the frequencies you need amplifying, other hearing aids just make everything louder which makes them uncomfortable most of the time."
>
> "What distinguishes BioAid from the competition is the availability within the app of multiple settings to meet the needs of different types of hearing loss."

Finally, in many cases BioAid is having an important impact even for those who chose not to use it as a long-term solution to hearing impairment. Online discussion, both between users and with the developers, illustrates how BioAid has contributed to enhanced dialogue on this subject [11] [12]. Even if short-term use of BioAid acts as a means of encouraging users to visit a clinician for a full consultation, this can still be considered an important aspect of this impact.

5. Sources to corroborate the impact [All sources saved on file with HEI, available on request]

[1] BioAid, 2013. *Smart Phones Meet Hearing Aids* [online] Available at: http://bioaid.org.uk/project.html [Accessed 7 June 2013]

[2] BioAid, 2013. *The biologically inspired hearing aid* [online] Available at: https://www.facebook.com/bioaidapp [Accessed 14 June 2013]

[3] Clark, 2013. *iTunes* [online] Available at: https://itunes.apple.com/gb/app/bioaid/id577764716 [Accessed 14 June 2013]

[4] University of Essex, 2013. *Mobile app turns iPhone into a biologically-inspired hearing aid* [online] Available at: http://www.essex.ac.uk/news/event.aspx?e_id=5095 [Accessed 7 June 2013]

[5] University of Essex report, 2013. *One video – BIG impact*

[6] BioAid, 2013. *BioAid in the press* [online] Available at: http://bioaid.org.uk/press.html [Accessed 7 June 2013]

[7] BioAid penetration – Download report, August 2013

[8] BioAid download coverage report, August 2013

[9] BioAid popularity ranking report: Ranks 2013-10May

[10] BioAid, 2013. *Testimonials* [online] Available at: http://bioaid.org.uk/testims.html [Accessed 6 June 2013]

[11] The Engineer, 2013. *Free app turns phone into a hearing aid* [online] Available at: http://www.theengineer.co.uk/medical-and-healthcare/news/free-app-turns-phone-into-a-hearing-aid/1015912.article [Accessed 14 June 2013]

[12] alldeaf.com, 2013. *Open source hearing aid algorithm* [online] Available at: http://www.alldeaf.com/hearing-aids-cochlear-implants/109211-open-source-hearing-aid-algorithm.html [Accessed 7 August 2013]