Report of the Lifelong Health and Wellbeing Exploratory Workshop on Transformational Approaches to Improving Hearing Aid Technology

3rd – 4th June 2014

Introduction

Improved treatment of hearing loss is an area of unmet clinical need that affects a large proportion of the older population. Scoping studies and a previous workshop held in 2012 have highlighted the potential for the cross-Research Council Lifelong Health and Wellbeing (LLHW) programme to bring a broad range of research disciplines and sectors together to develop novel approaches to improving hearing aids for enhanced health and wellbeing.

The Problem

Age-related hearing loss (Presbycusis) is thought to affect 55% of the UK population over 60. It is a degenerative condition that not only changes a person's ability to hear quiet sounds, but it also reduces the quality of the sound that is heard. Once the inner ear (cochlea) hair cells become damaged, they will remain damaged for the rest of a person's life.

Hearing aids are the most common form of treatment for mild to moderate hearing loss. Hearing aids pick up sounds through a microphone and convert them into electronic signals which are amplified to compensate for a person's hearing loss. Amplified signals are passed to a tiny loudspeaker where they are converted back into louder sounds that are easier to detect by the damaged hair cells.

However, adoption of hearing aids by patients is low (15-20% regularly use their device) due to relatively poor performance. The primary complaint of hearing aid users is poor sound quality and that they can't discern specific voices in a crowd or noisy environment.

There has been considerable international research effort for many years to improve understanding of the effects of hearing impairment and the performance of hearing devices. Despite major advances in knowledge of the function of the auditory system, progress towards improved devices remains slow.

Hearing research in the UK is a small but internationally leading field with groups specialising in speech perception, psychoacoustics, communication, hearing devices, and biological or pharmacological treatments strategies. There is potential for greater networking in the UK with the wider engineering and Information Communication Technologies (ICT) communities in particular translating cutting edge research in digital signal processing, machine learning and algorithm development in novel ways that have not been applied to date in hearing research.

The Challenge

A joint MRC EPSRC exploratory workshop held in June 2012 involved key members of the academic and industrial hearing research communities. This group identified the need for greater collaboration between the medical, psychological, audiological, engineering, ICT and physical sciences research communities in order to develop novel solutions to improving hearing aids. The following potential areas of research opportunity were highlighted for further exploration:

Hearing aid device improvements:

Currently hearing aids are functionally inflexible and once fitted are unable to adjust to real time changes in the environment or changing user needs. A device with improved communication and self-tuning capability could react to changing auditory conditions and/or the wearer's response to deliver better sound quality.

Improved neurometric testing:

The current system for evaluation of hearing, the audiogram, measures the quietest sound detectable across a range of frequencies and is unchanged for 40 years. New technologies in sensor development, signal processing and imaging could be applied to measure and interpret activity patterns and structural changes at all levels of the auditory system; enabling quantification of hearing loss and greater customisation of hearing aids for the individual.

Aim of the follow up workshop

A follow-up workshop was held in June 2014 to develop these initial ideas further and to identify any additional areas of research need related to the improving hearing devices where a multidisciplinary approach could produce a step change.

Aims of the workshop:

- To explore in greater depth areas of opportunity for novel, multidisciplinary research to improve hearing aid technology and methods for testing hearing performance.
- To draw in expertise currently not focussed on hearing, share expertise and build appropriate collaborations.

The workshop was chaired by Prof Tim Griffiths, Newcastle University and MRC Neurosciences and Mental Health Board member, and attended by around 30 attendees from the NHS, Action on Hearing Loss, hearing aid manufacturers, and academic experts working in the areas of:

- Hearing aids and hearing loss (clinical)
- Hearing (preclinical)
- Ultrasound imaging
- Signal processing and machine learning
- Device miniaturisation and low-power systems
- Sensor development

The workshop was an interactive event spanning two days with a programme of talks from expert speakers and users to inform a series of discussion sessions in groups and in plenary. A workshop dinner and informal networking time encouraged conversation and collaboration building. (See meeting agenda and participant list in **Annexes 1 & 2**).

Workshop Report

Day 1 – Describing the challenge

The workshop began with initial networking session and scene-setting talks from Dr John Day and Prof Michael Stone on current methods for testing hearing and the state of the art in hearing aid technology. A list of suggested reading provided by Prof Michael Stone, Dr Michael Akeroyd and Dr Bill Whitmer was circulated to workshop participants prior to the event.

Participants were divided into four groups with a mix of expertise to share knowledge and discuss the nature of the patient need in each area. Groups were asked to identify broad research challenges to address gaps between current technologies/methods and patient needs.

The four groups then combined into larger groups to share thoughts, leading to a combined list of initial research challenges associated with each area.

Research challenges identified in improving hearing aids included:

Speech in noise

- Noise reduction algorithms are insufficient at present, improved algorithms are needed to capture and better transmit intelligibility in sounds
- Improved understanding is needed of how signals are processed in a noisy environment by a non-hearing impaired person

Power

- Power - battery life is under additional demands in advanced aids, can energy harvesting be used to extend the life of batteries or even create a self-sufficient device?
- Can remote computing and improved communication between hearing devices and hand held computers be used to reduce the power and technology demands of hearing aids – i.e. all processing and transduction elements no longer need to be integrated in a single device.

Technology

- For those patients who require audiologist intervention, can remote monitoring/control be used for audiologists to communicate with the patient outside of the clinic and remotely programme the hearing aid to improve usability?
- Can speech recognition technology be used to sample preferred voices (e.g. partners) and programme hearing aids to select a preferred speaker from background noise?
- Can electroacoustical tests be routinely used in situ to check if the signal processing features of a hearing aid working to specification?

Signal Processing

- Replicate intelligibility of sounds in natural hearing
- Measure intelligibility of sounds delivered
- Transfer some of the signal processing from the brain to the hearing aid
- Better understand hearing cues to inform processing strategies and enable appropriate perception
- Different strategies for handling speech are needed along with adaptive technology to enable the hearing aid to react intelligently to changing hearing environments.

Personalisation

- How can different patient cohorts be identified in order to tailor personalised solutions to their needs?
- Can integration with, for example, smart phone technology offers opportunities for device optimisation
- Create hearing aids that are compatible with the hearing needs and strategies developed by the impaired person – can we better understand the intent of the listener so that the hearing aid can respond accordingly?
- Develop self-learning devices that can adapt to the hearing needs of the user and in turn teach the user, adapting previously learned strategies for hearing

- Developers need to communicate to providers and users the improved functionality of modern hearing aids and how these should be used for maximum benefit.

Research challenges identified in testing for hearing:

- Can hearing loss be diagnosed from auditory nerve output?
- Psychophysical and neurological tests are needed to predict speech in noise detection
- Develop an objective measure for performance to go beyond self-report; for example a dynamic perturbation test better describe how the cochlea is working.
- Assess which are the tests that give a good picture/measure of hearing. What does each test add to evidence to inform the clinician/researcher?
- Better imaging technologies including improved EEG testing/processing
- Link neurometric tests with other forms of test to inform development of the right intervention
- New/improved testing methods have to be cost-effective and practical to employ.
- Early diagnosis is key – can differentiation of sub-hearing loss provide information about what is wrong? E.g. outer/inner hair cell loss

Personalisation

- Objective measures in dynamic environments could enable personalised interventions
- Develop tests appropriate to patient abilities that help make decisions on patient intervention

Use of models

- Could a model system be used to estimate stimuli, benchmark tests and pathology and inform directed interventions? Could this also be used for predictive modelling?
- Simulations of the process of hearing in hearing impaired people could be used in diagnosis, e.g. to demonstrate the extent of the problem. A standardised simulator is needed to generate and inform research, however the number of variables is huge – how best to manage these?

Day 2 – Exploring the problem

The following key challenges identified on Day 1 were developed in group discussion during Day 2:

- Optimising devices for individuals
- Measures of natural hearing
- Tests to predict speech in noise deficiencies
- Improving speech in noise performance in devices
- New models of hearing
- New methods of transduction

Participants were able to choose which research challenge(s) they wished to explore in greater depth and were also able to suggest additional topics for discussion.

In order to identify research gaps and opportunities associated with each challenge, groups were asked to capture from their discussions; the nature of the research challenge, what needs to be done, who should be involved and what could help facilitate progress. The following tables provide a synthesis of these discussions.

Exploring The Research Challenge – 1) Optimising devices for individuals

What is the research challenge?	What needs to be done?	Who should be involved?

• To link specification of devices to results of audiology testing in order to address patient specific needs.
• To develop different models for device operation and self-learning – harvesting information from the patient's auditory environment
• Consider pre-fitting characterization (input to fit) and post fitting individualisation (adapting technology) both should be studied and long-term benefit should be compared
• Reduce power demand – potential for energy harvesting?
• To develop interactive technology between user and device to inform learning strategies on both sides
• To understand how to best classify individuals to inform personalisation of devices – by environment, cognitive ability, pre/post fitting performance? Requires an understanding of the demographics and cultural influences of patient groups and best use of available tests.
• To develop a framework for optimisation based on understanding
	• Be clear about what can and cannot be achieved by personalisation – e.g. independence?
	• Inspire others in other disciplines who may not link their research to this area
	• Provide remote audiology and technological support during adjustment phase
	• User independence needs:
	  • Classification of needs of users
	  • Consistent device performance monitoring and tolerance to variable conditions
	  • Devices robust to physical conditions and power efficient (implantable maybe a solution where appropriate, implants too will enable access to the solution at acceptable cost)
	• Reform clinical hearing aid fitting protocol
	• Improve the signal processing algorithms in conventional hearing aids. Combined with greater personalisation could produce real improvements for the patient.
		Expertise in
		• Clinical psychology – understanding aspirations of patients
		• Machine Learning – data challenge
		• Signal processing
		• Bioinformatics
		• Speech technology
		• Music information retrieval
		• Human Computer Interaction (HCI) and design and ergonomics
		• Human communications in ICT
		• Data mining of records in a trusted repository
		
		What could help facilitate progress?
		
		• A national survey of hearing aid users to assess expectations and aspirations
		• National register of people with hearing impairments
		• Screening to diagnose early stage hearing loss
		• Greater competition to produce game-changing innovation
		• Open data set that can be accessed without ethics clearance (accepting that there will be challenges with

what the patient wants from the device • To have feedback from the device on usage to inform further optimisation • Develop self-optimisation capability from knowledge of user overtime – allowing for different solutions for different lifestyles and auditory needs. • Consider how personalisation could be evaluated? What measures used?		this) • Knowledge about individuals – different market segments and situations – e.g. speech in quiet, noisy, complex environments • Consider at early stage on how to bring any idea to market. Interact with audiology industry, including global hearing aid provision systems

Exploring The Research Challenge – 2) Measures of natural hearing

What is the research challenge?	What needs to be done?	Who should be involved?
• To be able to measure people's behaviour in the natural environment and determine how this is controlled by hearing ability o There are currently no quantifiable measures of listening. o Logging of different auditory environments is quite crude, e.g. music, noisy conversation o Many people do not cognisant of their daily auditory experience	• Must be able to replicate/test in the individual's environment – e.g. suitable for city, country, home, office, etc. • Have to be able to measure how hard it is to listen in an environment • Data to include activities plus feedback from the user • Data needs to be linked and tied to qualitative evaluation, i.e. user commentary • Acoustic signal also needs a classifier – analysing the data real time • Need to monitor/evaluate suitability	• People who understand acoustics • Urban geographers, civil engineers – environment design • Acoustic engineers • Data analysts – big data challenge to be able to identify key parameters and extraneous data • A statistically valid user group • Need a control group

	of hearing aid for the individual and adaptations by the user as a consequence	

Exploring The Research Challenge – 3) Tests to predict speech in noise deficiencies

What is the research challenge?	**What needs to be done?**	**Who should be involved?**
• How to measure speech in noise deficiencies to guide development of effective interventions • Must be clinically feasible and practical • Self-testing (1st step) followed by clinical testing to identify underlying issues • What is/are the measures of top down process that matter for speech in noise ability, type/ degree of intervention	To develop appropriate tests: • Biological roots of speech in noise deficiencies need to be better understood • Consider needs of populations across different ethnic/cultural groups and accessibility issues of each • Retain testing of cognitive speech of hearing improvement • Design outcomes that stratify patients toward appropriate interventions • Consider translation pathway strategy upfront - involve clinical research from the beginning in order to take research into practice. Research applications should show a dissemination strategy beyond publication.	• Neurocognitive imagers and psychologists • Linguists • Audiologists • Behavioural therapists • ENT clinicians • IT Technology **What could help facilitate progress?** • Coordinated research programme • Access to novel audiology and technical components • Overarching consortium to direct research strategy and coordinate multi-stakeholder engagement

Exploring The Research Challenge – 4) Improving speech in noise performance in devices

What is the research challenge?	What needs to be done?	Who should be involved?
• Need a good model for speech intelligibility in normal hearing humans to inform strategies for replicating this in hearing aids. • The machine learning field is moving away from speech enhancement • Can trainable neural networks be utilised to improve intelligibility? • How could a neural network be placed onto a hearing aid? Would computing power need to be offloaded to an external device? • Developing robust neural networks for a range of environments requires lots of data	• Improve single channel noise reduction – train device for background noise and speech using binary mask approach? • Generate an ideal binary mask – potential for multi-channel sources? How would source segregation be dealt with? Requires number of detectors and stationary mixing matrix – e.g. multiple microphones on glasses. • Bring together speech worlds and neural network communities • Need to better classify temporal aspects of noise • Train networks to recognise individual voices as in natural hearing • Could relay systems help understanding of the environment? • Change of approach - move away from just thinking about speech in noise reduction to perception. When talking about speech move away from the spectrogram as the measure of perception.	• Speech and neural networks communities • Audiologists – to inform models and networks tailored for the hearing impaired • Communications groups **What could help facilitate progress?** • Issue challenge to UK communities followed by a meeting to progress ideas – the key is articulating challenges • A community champion

Exploring The Research Challenge – 5) New models of hearing

What is the research challenge?	What needs to be done?	Who should be involved?
New models for hearing are needed to address the following needs: • Cannot predict impairments of an individual effectively • Not enough objective measures of brain processing/cognition/listening • Models of speech recognition do not reflect lower limits of hearing ability • Lack of understanding of the auditory nerve and its role in hearing loss • Lack of understanding of brain function in normal hearing and impaired hearing – e.g. the learning/response to hearing rehabilitation	• Bring speech recognition and hearing impairment communities together • Routing methods for hearing-alternatives to impaired method • Unstructured data known by audiologists needs conversion into useful metrics to construct models • Data selection and capture by the user to identify challenging situations.	Multidisciplinary research • audiologists, • signal processors • Cochlea instrument researchers • neurologists, • human communications, • Rehabilitative approaches – stroke/hip replacement/speech therapy • How can we get neuroscience community to recognise that they can contribute? • Gaming experience evaluation community **What could help facilitate progress?** • International open competition to stimulate innovation • Networking environment (national) • Grand Challenge programme • Need for evaluation and validation

Exploring The Research Challenge – 6) New methods of transduction

What is the research challenge?	What needs to be done?	Who should be involved?
• Transduction of an uncoded signal in its totality to reproduce naturalistic hearing • Potential new approaches for transduction haven't been explored • Are there possibilities for direct stimulation of the tempanic membrane that could cut down feedback and possibly reduce power needs? • What would the effect on remaining hearing be? • Would it be efficient? • Could a device on a new window in the middle ear be used to stimulate the cochlea? • New methods of transduction could be based on models of the simulated response to dynamic excitation • Can bone anchored hearing aids be optimised to help more people with certain classes of impairment?	• Investigate fluid mechanics, identify optimum location of an implant and how a device could be anchored. • Can the vestibular canal be stimulated with ultrasonics to reduce loss typical in a surgical solution by having a single unit device? Could this improve efficiency and consistency? If not better with a non-invasive device • Still need to understand more about the impaired auditory system (physiology and neural complex, row of outer hair cells) and explore the nature of transduction at the cochlea • Could tactile information supplement acoustic information to enhance listening? Can we learn from the stimulation of patients who don't have a cochlea – akin to supporting with sign language using different sensory information	• Surgeons and audiologists • Biomedical engineers • Solid and fluid mechanics • Microfluidics • Comsol modelling, multiphase physics, FET modellers (solid/fluid interactions) • Acoustics for solving wave equations • Material scientists **What could help facilitate progress?** • Wide range of expertise needed • A network would help explore possibilities and result in specific research ideas for future proposals • Industry participation to bring vital real world perspective • Opportunity for single idea to for a stand-alone grant application

Additional topic suggested – 'The Hearing Aid Challenge'

What is the research challenge?	What needs to be done?	Who should be involved?
Make a better speech enhancer algorithm for a hearing aids. To achieve this: • Design a 'Challenge' competition to encourage greater participation and innovation • Research Councils/charities provide an open access set of ear recordings in various settings • Entrants use recordings to design, train and refine improved algorithms in own research setting • Outputs from new algorithms sent to a test panel of hearing aid users to assess results vs standard technology	• Convene a national panel of hearing impaired volunteers (~100?) • These listen to outputs and score/grade/recognise improvements in speech perception • Small prizes awarded to best entrants • Challenge followed by a workshop and proceeding papers, encouragement to apply for funds to develop roll-out algorithms	• Charities, Research Councils and other stakeholder groups • Volunteer panel of assessors • Industry • Algorithm developers from all fields **What could help facilitate progress?** • Seed corn money from the Research Councils for publicity/conference • Support from Action on Hearing Loss to establish a panel of volunteer assessors • Industry engagement to ensure take-up of successful algorithms

Workshop Outcomes

In a final plenary session the following key points were agreed by participants:

- The six areas identified had potential for novel multidisciplinary research:
    - Optimising devices for individuals
    - Measures of natural hearing
    - Tests to predict speech in noise deficiencies
    - Improving speech in noise performance in devices
    - New models of hearing
    - New methods of transduction

- Collaborative and broad ranging input is needed to address many of the most challenging barriers to improving hearing aid technology. Other disciplines need to be encouraged to engage in this research agenda.

- It was clearer from this workshop how representatives from engineering and ICT disciplines could contribute skills and knowledge and how disciplines currently outside of the hearing research community could be involved.

- There are multiple possibilities to optimise devices for the individual for increased patient benefit. In particular, the following have potential to produce a step-change in current device technology:
    - Novel algorithms and signal processing techniques from outside of hearing research to improve speech in noise performance of devices
    - Machine learning technology combined with existing hearing research to create more responsive devices
    - Models of impaired hearing to inform the development of personalised hearing aids
    - Long-term studies to understand patient needs

- Better engagement with audiologists and clinicians earlier on in the research process is needed to inform research directions and build a larger collaborative workforce to tackle these problems.

- Industrial engagement in research is vital to achieve buy-in of developers and manufacturers and ensure research outputs are appropriate for translation.

- The involvement of users in research via collaboration with the NHS and hearing charities such as Action on Hearing Loss will ensure new technologies best meet patient needs and take-up of improved devices is increased.

Next Steps and Funding Opportunities

All delegates were urged to pursue new links and possibilities for research collaborations initiated at this workshop.

EPSRC and MRC encourage the development of cross-sector, cross-disciplinary proposals for funding to improve hearing aids to enhance health and wellbeing. Proposals can be submitted at any time through existing funding mechanisms:

- Support for multidisciplinary research, including research on hearing, can be applied for via individual Research Council response mode funding. Details of how to apply can be found on the EPSRC and MRC websites.
- The cross-Council funding agreement allows the research Councils to collaborate on the assessment and funding of multidisciplinary proposals.
- Collaboration with industry is particularly welcomed in this area. The research costs of academic/industry research collaborations can be supported through Research Council grant funding.
- There is strategic alignment to the MRC Neurosciences and Mental Health board, and to EPSRC Information and Communication Technology panels for technology-led solutions. This should be highlighted in any future applications.

Following the workshop MRC and EPSRC agreed to fund a joint call for networks with the aim of building new multidisciplinary and cross-sector collaborations that will further explore areas for potential multidisciplinary research to improve hearing aids.

In parallel, EPSRC will hold a call for research projects to address some of the technological challenges highlighted in this report.

END

Annex 1

LLHW Exploratory Workshop on Transformational Approaches to Improving Hearing Aid Technology

Outline Agenda
Chair: Professor Tim Griffiths, Professor of Cognitive Neurology, Newcastle University and MRC Board Member

Aims of the day:

- To explore in greater depth areas of opportunity for novel, multidisciplinary research.
- To draw in expertise currently not focussed on hearing, share expertise and build appropriate collaborations.

Day 1	
Registration and Lunch **Chairs' welcome and introduction**	12.30 13.30 – 13.45
Setting the scene • High-level talks to provide an introduction to the area • Group based discussions of current hearing aid and diagnostics technology in relation to user need	13.45 – 15.00
Break (Tea & Coffee)	15.00 – 15.30
Exploring the problem • Group discussions of current gaps in knowledge and research needs	15.30 – 16.45
Break (Tea & Coffee)	16.45 – 17.00
Feedback from group discussions	17.00 – 18.00
Day 1 close – delegate check-in	18.00
Pre-dinner drinks Delegate dinner	19.00 19.30
Day 2	
Welcome and introduction to the day	09.00 – 09.30
Identification and exploration of research challenges	09.30 – 12.00
Lunch	12.00 – 12.45
Round-up of outputs	12.45 – 14.00
Workshop Close	14.00

Annex 2

LLHW Exploratory Workshop on Transformational Approaches to Improving Hearing Aid Technology

Participant List

Name and title	Institution
Dr Trevor Agus	Queen's University, Belfast
Dr Michael Akeroyd	MRC Institute of Hearing Research
Dr Steve Bell	University of Southampton
Dr Stefan Bleeck	University of Southampton
Professor Peter Brett	Brunel University
Professor John Culling	Cardiff University
Professor Adrian Davis	Public Health England
John Day	North East Wales NHS trust
Professor Thomas Hain	University of Sheffield
Dr Heike Heuermann	Siemens
Dr Ralph Holme	Action on Hearing Loss
Dr Morten Løve Jepsen	Widex
Professor Simon King	University of Edinburgh

Professor Corne Kros	University of Sussex
Professor David McAlpine	University College London
Dr Carmel Moran	University of Edinburgh
Dr Graham Naylor	Oticon
Professor Mark Plumbley	Queen Mary University of London
Professor Nader Saffari	University College London
Professor Leslie Smith	University of Stirling
Professor John Soraghan	University of Strathclyde
Dr Michael Stone	University of Manchester
Ruth Thomsen	Imperial College Healthcare Trust
Dr Richard Turner	University of Cambridge
Gemma Twitchen	Action on Hearing Loss
Dr William Whitmer	MRC Institute of Hearing Research