The cover picture illustrates a method used in the National Acoustic Laboratories for displaying transient evoked otoacoustic emissions, which represent the level of activity of the outer hair cells of the cochlear (inner ear). Such pictures can be compared for the left and right ears of the same person, for the same ear at different times, or for the ears of different individuals. This approach is being used to study the differences between aging for noise-exposed and non-noise-exposed ears.

The picture shows how the level of activity, over a range of frequencies, changes during the period from the time the ear is stimulated with a click until 16 thousandths of a second later. The cooler colours represent low activity (white means no measurable activity) and the warmer colours represent high activity. In this example, an average of men over 55 years old, the greatest activity is around 2000 Hz at 5 ms after the click but this shifts to 1000 Hz by 11 ms after the click. The technique is proving valuable in studying how the ear functions and what happens when the ear is damaged by noise or other harmful agents.
Contents

RESEARCH DIRECTOR’S OVERVIEW 1

HEARING AID AND REHABILITATION RESEARCH 3

Hearing Aid Fitting and Design 4
Evaluation of NAL-NL1 4
Comparisons of NAL-NL1 prescriptions with other non-linear hearing aid fitting procedures 6
SHAPE - A broader view of hearing aid fitting objectives and strategies 7
Effects of different input levels and signal-to-noise ratios on preferred amplification characteristics 8
A self-consistent set of hearing aid correction figures 10
Fitting low ratio compression to people with severe and profound hearing losses 12
The mechanisms of wind noise in hearing aids 13

Special Issues for Children, Cochlear Implantees, Aboriginals and Torres Strait Islanders 15
Is the clinical paired comparison test for hearing aid evaluation a useful and reliable tool for optimising amplification for severely/profoundly hearing-impaired children? 15
Fitting hearing aids to children who also use cochlear implants 16
The effects of sound field classroom amplification on the communicative interactions of Aboriginal and Torres Strait Islander children 18

HEARING LOSS PREVENTION AND NOISE RESEARCH 21

Hearing Loss Prevention 22
Longitudinal study of a non-noise exposed cohort comparing click-evoked otoacoustic emission techniques and pure tone audiometry 22
Hearing status of Aboriginal prisoners 25
Modelling transient evoked otoacoustic emissions in noise-induced hearing loss 26

Noise Investigations 31
Noise exposure reduction for musicians 31
Warringah Council - NSW WorkCover Authority project 31
Sydney Airport health study 32
Traffic noise sleep study 32

ENGINEERING RESEARCH 33
Acoustic shock protection and intelligibility enhancement for telephone operators 34
Hearing aids and CDMA digital mobile phones 35
High current limitations of hearing aid batteries 36
Potential gain limitation for digital hearing aids 37

SCIENTIFIC COMMUNICATIONS 39
Publications 39
Conferences and Presentations 40
Visitors 41
Library 41

APPENDICES 43
Publications 43
Presentations and talks 44
Visitors 45
Products 46
Staff

Research Director
Denis Byrne, PhD

Deputy Research Director
Harvey Dillon, PhD

Executive Officer
Mei So, MSSc

Research Scientists
Eric LePage, PhD
Teresa Ching, PhD
Gitte Keidser, PhD
John Macrae, PhD (retired Sept.1998)

Other Research Staff
Richard Katsch, BSc
John Seymour, BSc
Narelle Murray, MA (Aud)
Robyn Massie, BSpthy, MAud
Amanda Hill, BA (Hons), Dip.Aud.
Dan Zhou, MSc

Engineering and Technical
Eric Burwood, MEngSc
Wally Crichton

Library
Joy Fischer, BA, Reg. Cert. of L.A.A

Co-operative Research Centre Grant Staff
George Raicevich, MEng(Elec)
Lydia Storey, BA, Dip.Aud.
Amar Gorur, M.Tech.
John Coelho, BE(Hons)
Michael Fisher, BE(Hons)
Frances Grant, BA, Dip.Aud.
Scott Brewer, BA,App.Sci.

Externally Funded Research Staff
Inge Roe, BSc(Hons)

Australian Hearing Research Committee
Dr John Bench (Chair)
Dr Victor Bear
Dr Denis Byrne
Mr Peter O’Byrne
Dr Jenny Rosen
Ms Sharan Westcott

Staff from other areas of
Australian Hearing who have contributed
to research activities
Chris Barker, BA(Hons), Dip.Aud

Engineering Services
Peter Always, BSc
Bob Cook
Peter Peploe, BE., Dip. Telecommunications
Warwick Williams, MEngSc., MA

Visiting Scientist
Åke Olofsson, Karolinska Institute, Stockholm,
Sweden

Note: E-Mail addresses in the form Denis.Byrne@nal.gov.au
Research Director's Overview

It is my pleasure to present the National Acoustic Laboratories' (NAL) 1998/99 Annual Research and Development Report. This regular report, first published in 1993, was conceived primarily as a vehicle for sharing research findings and ideas with professional colleagues. However, it is clear that the report is serving a more general purpose in increasing community awareness of the research conducted in Australian Hearing by its research arm, NAL. For this reason we aim to make the thrust of each project clear to the general reader although the technical details may be accessible only to colleagues with the relevant professional backgrounds.

NAL's major areas of research, hearing aids and hearing loss prevention, are both undergoing rapid changes. This presents both opportunities and challenges and NAL is especially well placed to make important contributions, thus serving the Australian community and the world of science more generally.

Hearing Aid Research

Hearing aids are undergoing a period of exceptionally rapid technological development. A major challenge is to make the most of the advantages of new technology by devising effective fitting methods for advanced hearing aids. A large part of the hearing aid research effort for this year has been focused on refining and validating a new NAL procedure for fitting advanced hearing aids. Another project, commenced during the year, is designed to examine hearing aid fitting objectives more comprehensively than has been past practice. Now that hearing aids have far greater capabilities, what should the objectives be in designing and fitting such aids to enhance all aspects of auditory experience?

Several projects were devoted to optimising amplification for people with hearing impairments who have special needs. These include severely hearing-impaired children, Aboriginal and Torres Strait Islander children, and people who use a hearing aid in one ear and a cochlear implant in the other.

Cooperative Research Centre

As in previous years, much of the hearing aid research was conducted as part of the Cooperative Research Centre (CRC) for Cochlear Implants, Speech and Hearing Research. The seven-year grant that supported this CRC concluded at the end of the year. It is extremely gratifying that an application for a new CRC, with the same four major parties, was successful. This will be called the CRC for Cochlear Implant and Hearing Aid Innovation. The four major parties are Australian Hearing, the Bionic Ear Institute, Cochlear Pty Ltd, and the University of Melbourne. The new CRC will support a substantial hearing aid research effort over the next seven years. Its awarding is recognition of the work of the previous CRC in both the hearing aid and cochlear implant areas.

Hearing Loss Prevention

A very significant contribution to hearing loss prevention was the publication in the Medical Journal of Australia of research on ear damage arising from the use of personal stereo headsets. It was shown that frequent users of stereo headsets suffered ear damage comparable with that of people working in noisy industries. Even greater damage occurred for people who worked in noise and listened through personal headsets. This study refuted the previously prevailing view that the risk of damage from recreational noise, apart from shooting, is minimal. The new findings arise partly from the use of a more sensitive measure of ear damage and partly occur because personal headsets have now been in regular use for long enough for substantial amounts of damage to have accrued. Some details of this publication are given later (see Publications) and a report of the study was included in the 97/98 Research and Development Report.
Research with the technique of measuring otoacoustic emissions (sounds generated by the ear and reflecting how well it is functioning) has resulted in significant improvements in the technique. A highlight of the year was collaborating with a major equipment manufacturer so that these NAL inventions will be incorporated into future commercial equipment for Australian Hearing and general use.

**Hearing Aids and Mobile Telephones**

A continuing consumer concern is the extent to which people wearing hearing aids will have access to the benefits of digital mobile phone technology. When the first such telephone system (GSM) was introduced in Australia in 1993, NAL conducted an extensive investigation of interference problems, in collaboration with the telecommunications and hearing aid industries. Towards the end of this year, NAL began to investigate a new technology (CDMA) that is planned for introduction in 2000. The initial stages of this work are summarised in this report (see Engineering).

**Retirement of Senior NAL Scientist**

In September 1998, John Macrae, Ph.D., retired after a long and very distinguished career as a NAL research scientist. John joined NAL (then the Commonwealth Acoustic Laboratories) in 1959. He spent almost all his working life in NAL and authored over 120 scientific publications. Outstanding achievements include his extensive investigations of the risk of hearing damage from hearing aid use, his studies of the acoustic effects of variations in earmolds and hearing aid fittings, his development of the percentage loss of hearing aid tables that are the basis of most Australian compensation assessments, and his contributions to hearing aid specifications and noise management Standards.

I take this opportunity to publicly acknowledge John's vast contributions to NAL research and to wish him a happy retirement.

**Professional and Public Communications**

Over 20 NAL scientific articles were published during the year. Other articles were written for publications for people with hearing impairments or parents or teachers of hearing-impaired children. Research staff gave numerous conference presentations or other public talks and, as usual, they served extensively as a source of expert advice for other people within Australian Hearing, outside professionals, and members of the public. Major conferences in which NAL scientists participated, usually as keynote or invited speakers, included: 6th Asia-Pacific Conference on Deafness (Beijing), XXIV International Congress of Audiology (Buenos Aires), International Collegium of Rehabilitative Audiology (Vancouver), American Academy of Audiology (Miami), Jackson Hole Rendezvous (Wyoming), A Sound Foundation Through Early Amplification (Chicago), EHIMA World of Hearing (Brussels), Noise Effects '98, 7th International Congress on Noise as a Public Health Problem (Sydney). Details of NAL publications and talks are presented later.

The processes of publishing and participating in conferences serve the dual purposes of communicating NAL research findings, including NAL-developed procedures, to all who wish to use them and of providing NAL scientists with opportunities to benefit from interactions with leading overseas scientists.

**NAL Hearing Aid Conference**

NAL, in collaboration with the CRC, presented the conference “Hearing Aid Amplification for the New Millennium” from 15-19 November 1999. The first day was a seminar on the theme of scientists and consumers working together. In particular, the discussions addressed the questions of why hearing aids are not better accepted and of how future hearing aids should perform to be most useful to the wearers. The remaining four days were technical papers addressed mainly to audiologists, engineers, and other professionals. The conference was well supported and had a strong program of contributions from NAL and other scientists, including many from overseas.

**Inquiries**

Further information about any of the material in this report, or NAL research and development activities more generally, can be obtained from me or from any of the scientists or engineers associated with particular projects.

Denis Byrne
A major objective of NAL research is to extend knowledge of hearing problems and the needs of hearing-impaired people and how to assist them. The following two sections describe eight projects concerned with hearing aid research and four relating to the amplification needs of children, people who use a hearing aid in combination with a cochlear implant, and Aboriginals and Torres Strait Islanders.

The hearing aid research projects were largely oriented towards making the best use of current and future advanced hearing aids. Three specifically concerned NAL’s new procedure for prescribing non-linear amplification. Two other projects were concerned with requirements for future hearing aids, two with general fitting issues, and one with the long-standing, but little understood, problem of wind noise affecting hearing aid use.

The projects concerning people with special amplification needs produced gratifying results. Among other things, these projects have demonstrated that it may be valuable to use a hearing aid in addition to a cochlear implant and that the use of classroom amplification can change communication behaviours in desirable ways.

Research is hard work for 4½ year old Charlotte and teddy, pictured here with Sam Harkus.
Hearing Aid Fitting and Design

Evaluation of NAL-NL1

Investigators: Gitte Keidser, Frances Grant

Background: Last year NAL released a new formula (NAL-NL1), which prescribes amplification for non-linear hearing instruments (Dillon, 1999). The aim of the new procedure is to maximise speech intelligibility for a range of input levels while making the overall loudness of speech equal to or less than normal. Contrary to other fitting procedures for non-linear devices, which mainly aim at normalising loudness in each frequency band, the NAL-NL1 prescription tends to equalise loudness of speech bands across frequencies at least for mild and moderate hearing losses. The two rationales often result in very different prescriptions (see elsewhere in this Report). The principle of equalising loudness of speech bands is in agreement with earlier fitting procedures developed at NAL for fitting linear devices, and clinical evaluation of these earlier procedures suggests that loudness equalisation works well for average input levels (e.g. Byrne and Cotton, 1988). However, there is currently no data available to indicate which of the two rationales, loudness normalisation or speech intelligibility maximisation, is the best rationale for fitting non-linear hearing instruments.

Research questions: This study aims at determining whether hearing impaired people benefit from normalising or approximately equalising the loudness of speech bands. The study also investigates whether the NAL-NL1 rationale is most effective when implemented in a single channel or in a multiple channel system.

Procedure: Twenty-four subjects participated in the evaluation study. Eight subjects each had a mild, flat hearing loss, a moderate/severe, flat hearing loss, and a steeply sloping high frequency hearing loss. The study was divided into three experiments comprising a preliminary laboratory test, a field test, and a final laboratory test. So far only the first experiment has been completed. The aim of the preliminary laboratory test was to determine the preferred rationale (loudness normalisation vs. NAL-NL1) implemented in a two-channel scheme and the preferred number of channels implemented in NAL-NL1 (one or two) for average input levels. For implementation of loudness normalisation, the IH AFF protocol, comprising the Contour test (Cox et al., 1996) for measuring loudness growth functions and the Visual Input/Output Locator Algorithm (VIOLA) software (Valente and Van Vliet, 1997) to calculate targets, was selected. The IH AFF protocol was chosen because the Contour test is easy to implement and because it appears to apply loudness normalisation in its purest form. That is, for any frequency and any loudness category, the prescribed gains are the difference between the input level selected by normal hearing people and the hearing impaired person. Using a wideband compression threshold of a speech shaped signal of 46 dB SPL information about the prescribed gain curve and compression ratios were extracted from the VIOLA and the NAL-NL1 software, respectively. For a 65 dB SPL input level, NAL-NL1 prescribed less low frequency gain, and lower compression ratios, averaged across subjects, than did IH AFF. Fast attack and release times were used, and the maximum power output (MPO) was set half way between what NAL-NL1 and IH AFF each prescribes. The three schemes (single channel NAL-NL1, two-channel NAL-NL1, and two-channel IH AFF) were implemented in Knowles Experimental Processor for Acoustic Research (KEPAR). Each subject completed a round robin paired comparison test, using four replications, and a speech recognition test (BKB sentences) listening to speech in quiet and to speech in background noise. The male speech used was filtered to match the International Long-Term Average Speech Spectrum (ILTASS, Byrne et al., 1994) and the background noise was a traffic-noise (extracted from Widex’s Real-Life Environmental Sound Examples CD), which has a spectrum more weighted to low frequencies than speech.
Findings: Before the testing commenced the subjects were asked to adjust the level of each scheme to a preferred listening level for speech in quiet. After adjustment, the average overall level of speech produced by each of the three schemes was within 1.5 dB. In the paired comparison test, a scheme was assigned one point whenever it was preferred to another scheme. A maximum of eight points could be obtained if one scheme was consistently preferred to the two alternatives. On average, the two NAL-NL1 schemes received more points than the IHAFF scheme in both quiet and background noise. An analysis of variance and a following post-hoc analysis of mean revealed no significant difference in the preference score measured for speech in quiet. In background noise, the two-channel NAL-NL1 scheme was significantly preferred to the IHAFF scheme ($p < 0.01$), whereas the single channel NAL-NL1 scheme was significantly preferred to the two-channel NAL-NL1 scheme ($p < 0.05$). Statistical analyses were also performed on the individual data. When comparing the two rationales (NAL-NL1 vs. IHAFF) nine subjects significantly ($p < 0.05$) selected NAL-NL1 for listening to speech in quiet, while two subjects significantly selected IHAFF. In background noise, twelve subjects significantly selected NAL-NL1 while none chose IHAFF. The remaining subjects showed no preference for either rationale. With respect to number of channels (one vs. two), two-thirds of the subjects showed no preference for either NAL-NL1 scheme in both quiet and noise. In quiet, five subjects preferred one channel, whereas three subjects chose two. In background noise, seven subjects significantly selected one channel, and only one subject consistently preferred two channels. Finally, with respect to the speech recognition score all three schemes produced near one hundred percentage score in quiet. In background noise the two-channel NAL-NL1 scheme on average produced about 12 percent higher score than the IHAFF scheme. The difference was significant at the 0.5 percent level. There was no significant difference in the average score produced with the single channel and the two-channel NAL-NL1 schemes.

Significance: The results suggest that for average input levels NAL-NL1 is generally preferred to a loudness normalisation procedure based on individually measured loudness growth functions (IHAFF protocol: Contour test/VIOLA software), and that hearing impaired people perform better with NAL-NL1 in noise. The results also suggest that NAL-NL1 implemented in a single-channel scheme is preferred to the two-channel implementation when listening in noise.

References:
Comparisons of NAL-NL1 Prescriptions with other Non-linear Hearing Aid Fitting Procedures

Investigators: Denis Byrne, Harvey Dillon, Teresa Ching, Gitte Keidser, Richard Katsch

Background: The NAL-NL1 prescription procedure for fitting non-linear hearing aids was released in 1998. Clinician software, applicable to any hearing aid, is currently available and the fitting formulae will be incorporated into some manufacturers' custom fitting software in the near future. NAL-NL1 has been outlined by Dillon (1999) and will be presented in detail in future publications. This project addresses a commonly asked question which is "How does NAL-NL1 compare with other available procedures?"

Research Questions: What are the characteristics of NAL-NL1 prescriptions and how do they compare with the prescriptions of three other procedures?

Procedure: The prescriptions of NAL-NL1 and three other non-linear fitting procedures, were calculated for 13 varied audiograms. The other procedures were Fig6 (Killion, 1994), DSL [i/o] (Seewald et al, 1996) and a threshold version of IHAFF (calculated from data supplied by R. Cox). The similarities and differences between the prescriptions of the procedures were identified.

Findings: The figure illustrates prescriptions for NAL-NL1 and DSL [i/o] for a flat audiogram and for a steeply sloping high-frequency hearing loss. (DSL would prescribe more gain for the 50 dB SPL input if the CT were set lower.) Usually, the Fig6 prescriptions were similar to DSL [i/o]. IHAFF prescribed considerably more low-frequency gain than the other procedures except when the low-frequency hearing was near normal.

Conclusions based on the set of comparisons are:

1. For average input levels, NAL-NL1 prescriptions agree closely with those of the NAL-RP linear prescription procedure.
2. For most audiograms, NAL-NL1 prescriptions differ substantially from those of the other procedures.
3. NAL-NL1, compared with the other procedures, prescribes less low-frequency gain for flat hearing losses.
4. NAL-NL1 prescribes less high-frequency emphasis for steeply sloping high-frequency hearing losses.
5. NAL-NL1 usually prescribes lower compression ratios.

Significance: This study demonstrates that the NAL-NL1 procedure prescribes substantially different amplification from the currently popular alternatives. Further studies are examining whether the NAL-NL1 prescriptions are more, or less, effective than those of other procedures.

References
SHAPE - A Broader view of hearing aid fitting objectives and strategies

Investigators: Denis Byrne, Harvey Dillon, Gitte Keidser, Stig Arlinger (University Hospital of Linkoping, Sweden), Robyn Cox (University of Memphis, USA), Wouter Dreschler (Academic Medical Centre, The Netherlands), Stuart Gatehouse (University HNO Clinic, Giessen, Germany), Carl Ludvigsen (Welsh Hearing Institute, UK), Dafydd Stephens (Welsh Hearing Institute, UK), Hans Verschuure (University Hospital, Rotterdam, The Netherlands)

Background: The 95/96 NAL Research and Development Report referred to the SHAPE model in an item entitled “Shaping amplification for hearing-impaired persons”. It was argued that optimal amplification may be a compromise between what is required to optimise different auditory abilities. It was suggested that the type of amplification (frequency response) required to provide best speech understanding may emphasise high-frequency sounds more than the amplification that is best for the detection and localization of sounds. The current project is a development of this idea. It is based on the premise that hearing aid fitting should consider what is required to optimise all aspects of hearing rather than being based more narrowly on considering only some of the possible desirable objectives. At present, most attention is given to optimising understanding of speech and amplifying sounds to comfortable levels. Sound quality is recognised as being important but is not considered consistently and adequately. Other aspects of auditory experience, such as being able to detect and locate significant sounds and experiencing sounds as being appropriately located in space, receive little consideration. The project, initiated in NAL, has been taken up as a collaborative project by members of the International Collegium of Rehabilitative Audiology.

Research Questions: (1) To develop the SHAPE model by identifying possible fitting objectives and amplification strategies that are expected to achieve each objective; (2) To review what is known about the effectiveness of each strategy in achieving its objectives; (3) To identify where the strategies that meet one objective have disadvantages with respect to other objectives and, thus, to indicate where compromises may be needed; (4) To identify research questions that need to be answered to determine what is the best amplification, considering all objectives. The project also has the general aim of encouraging scientists and audiologists to take a broader view of hearing aid fitting objectives.

Procedures: The collaborators exchanged knowledge with regard to hearing aid fitting objectives and strategies. This initial exchange was followed by preparing an article that describes the SHAPE model by listing objectives, strategies and compromises, reviews the current state of knowledge concerning the significance of various objectives and the effectiveness of different strategies, and that identifies a set of questions for future research.

Findings: An article has been drafted. It will be reviewed and revised by the collaborators before submission to an international scientific journal.

The SHAPE model, which may be subject to further development, lists 12 fitting objectives. Seven objectives relate to understanding speech, in quiet and in noise and at soft, average and loud levels. The other objectives relate to sound quality, detecting sounds, localising and externalising sounds, listening comfort and convenience.

The literature review indicates that there is considerable research on the relationships of amplification strategies to speech understanding but relatively little research addressing the other objectives. This observation raises a series of questions about the relative importance of different objectives and about the effectiveness of strategies for meeting those objectives.

Significance: Publications and presentations resulting from this project should help to promote a more comprehensive view of fitting objectives. Such a view should encourage improved strategies for the design and fitting of hearing aids. An immediate outcome is that the questions that were generated suggest important areas for future research. This will lead to projects to be undertaken individually or collaboratively by the present or other researchers.
Effects of different input levels and signal-to-noise ratios on preferred amplification characteristics

Investigators: Gitte Keidser, John Macrae, Frances Grant, and Scott Brewer.

Background: Environmentally adaptive hearing aids and multiple memory hearing aids both aim at adjusting the amplification characteristic to suit different listening environments. In the former device the adjustments happen automatically, whereas in the latter device manual adjustment is required. To enable the best possible design of such devices it is important to understand what changes in linear and non-linear responses hearing impaired people can benefit from when the levels of speech and background noise vary together with changes in the spectral and temporal characteristic of the background noise. Scattered information is available in the literature, but no systematic investigation into the subject has been conducted.

Research question: What is the best linear and non-linear amplification characteristic (single channel and two channel) for different speech levels, type of background noises, signal-to-noise ratios (SNRs), and types of hearing impairment?

Procedure (Best linear response): Twenty-eight subjects completed an experiment to determine the best linear response in twenty diverse listening conditions (cf. nearby Table). Six subjects each had normal hearing, and a moderate, gently sloping high frequency hearing loss, and seven subjects had a mild, steeply sloping high frequency hearing loss. The remaining nine subjects had flat losses ranging from mild to moderate/severe. An adaptive test procedure was used to determine the best shape of the frequency response by varying the relative gain in low and in a high frequency band around the fitted NAL response. That is, whenever the gain was increased by 1 dB in the low frequencies, the gain was at the same time decreased by 1 dB in the high frequencies (or the other way around). During the experiment, the gain was adjusted in 2 dB steps in either direction to a maximum of ±14 dB. The crossover frequency between the low and high frequency band was individually selected depending on where the audiogram displayed the steepest slope. The frequency responses were simulated in a digital master hearing aid and by using two buttons on a touch screen the subjects could step through the range of responses. A touch on one button would result in an increase of the low frequency gain and consequently a decrease of the high frequency gain, whereas a touch on the other button would make the gains change in the opposite direction. For each new presentation the initial hearing aid setting was selected randomly among frequency responses that varied within ±8 dB of the NAL response, and the direction in which the gain changed was switched.

An overview of the twenty listening conditions

<table>
<thead>
<tr>
<th>Speech level</th>
<th>SI</th>
<th>Listening criterion</th>
<th>Quiet</th>
<th>Steady LF-weighted Traffic-noise</th>
<th>Steady Speech shaped Babble-noise</th>
<th>Impulse HF-weighted Coins dropping</th>
<th>Steady HF-weighted Air compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 dB SPL</td>
<td></td>
<td>Speech understanding</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Naturalness</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55/75 dB SPL</td>
<td></td>
<td>Speech understanding</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Naturalness</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70 dB SPL</td>
<td>0.4</td>
<td>Speech understanding</td>
<td>5</td>
<td>9</td>
<td>13</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>Reduce noise</td>
<td>6</td>
<td>10</td>
<td>14</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>60 dB SPL</td>
<td>0.7</td>
<td>Speech understanding</td>
<td>7</td>
<td>11</td>
<td>15</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>Reduce noise</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>
between the two buttons in a random fashion. 
Continuous speech and noise were presented 
monaurally in a TDH-49 earphone in a 
randomised order. Three repetitions were 
completed for each listening condition.

Findings (Best linear response): A 
measure called Excessive Variability (EV) was 
introduced to determine whether the average 
response selected by each subject for each 
language condition was reliable. If X1, X2 and 
X3 are the results of the first, second and third 
presentations then EV is the largest difference 
in gain between any pair of X1 and Xj that is 
accepted in order to consider the result as 
reliable. The value EV (= 7.25 dB) was 
determined by multiplying the critical Z value 
of 1.645 by the standard deviation value of the 
mean differences (X1-Xj) measured in 1660 
cases. In all, 342 observations out of 560 (61%) 
were accepted as reliable. The normal hearing 
listeners on average produced the highest 
number of reliable observations (14.8) followed 
by the subjects with a steeply sloping loss 
(13.9). Subjects with a gently sloping loss and 
with a flat loss on average produced 11.3 and 
9.8 reliable observations, respectively. This 
observation suggests that people with flat losses 
experience greater difficulty in forming reliable 
judgments in various listening conditions than 
those with sloping losses. The listening 
conditions that attracted the least number of 
reliable observations were the four Speech in 
quiet situations together with Speech 
understanding in background noise in the 
better SNR (SII = 0.7). A t-test for independent 
samples suggested that data for normal hearing 
listeners and subjects with flat losses were not 
significantly different (p > 0.05) and therefore 
could be pooled. This outcome also applied to 
the two groups of sloping losses. An analysis of 
the pooled data for flat and sloping losses showed 
that the data produced by the two type of losses 
were not significantly different (p > 0.05) in all 
but three listening conditions. These conditions 
were Reducing the annoyance of background 
noise (babble, and the two high frequency 
weighted) in the better SNR (SII = 0.7). 
Subjects with sloping losses tended to need a 
flatter frequency response with less low 
frequency gain than that preferred by subjects 
with flat losses. The top right figure shows the 
average responses selected by our subjects. The 
responses are identified by the amount of gain 
applied in the low frequency channel relative to 
the NAL-response. The figure demonstrates a 
preference for different frequency responses 
depending, in particular, on the 
spectral shape of 
background noise. 
An asterisk marks the 
listening conditions for 
which the result is 
consistent across 
subjects on a similar 
ground to that chosen 
to accept reliability of individual observations.

Procedure (Best single channel 
compression scheme): A pilot study was 
completed to investigate whether there is a 
linear relationship between a given compression 
threshold and the preferred compression ratio. 
The hypothesis was that for any compression 
threshold the hearing impaired person will 
select a ratio that compresses the input range 
into a similar range of output. That is, the 
preferred compression ratio will increase as the 
threshold increases. Nine subjects completed 
the pilot study. Three subjects each had a 
moderate, flat hearing loss, a mild, steeply 
sloping hearing loss, and a moderate, gently 
sloping hearing loss. The hypothesis was tested 
for five different listening conditions (numbers 
1, 5, 6, 19, and 20 in the nearby Table) using 
four compression thresholds (45, 55, 65, and 
75 dB SPL), five compression ratios (1, 1.3, 2, 
4, and 100) and three replications. All 
compression schemes were simulated in a digital 
master hearing aid using fast attack and release 
times. For each listening condition and 
compression threshold, the subjects were 
presented with five hearing aids on a touch 
screen. The five hearing aids were assigned each 
of the five compression ratios in a randomised 
order. The subjects’ task was to select the one 
preferred in each listening condition.

Findings (Best single channel 
compression scheme): The average data 
from nine subjects confirmed the hypothesis, 
and suggested that the slope of the linear 
relationship is constant across the range of 
listening conditions. Therefore, an adaptive test 
procedure can be used to determine the best 
single channel compression scheme where the 
compression ratio is varied for a fixed 
compression threshold.

Significance: The results from this study will 
provide specifications for an environmentally 
adaptive hearing aid and will enable us to refine 
NAL’s current fitting guideline for multiple 
memory hearing aids.
A self-consistent set of hearing aid correction figures

(Partly funded by the CRC for Cochlear Implant, Speech & Hearing Aid Research)

Investigators: Lydia Storey and Harvey Dillon

Background: Increasingly, electrically programmable hearing aids are being used. The initial adjustment of these hearing aids is made by the programming software based on some characteristics of the client (threshold or loudness growth data) combined with the expected performance of the hearing aid in a 2 cc coupler or ear simulator. The target, however, is invariably a real ear gain – either in the form of Real Ear Aided Gain (REAG) or Real Ear Insertion Gain (REIG). To deduce how the hearing aid should be adjusted so that the real ear gain target is most likely to be met, various corrections factors must be applied.

The type of correction factor needed depends on the type of real ear gain target that is to be achieved. Killion and Monser (1980) conceived the term CORFIG, which stands for “coupler response for flat insertion gain” and which describes the correction figures that should be added at discrete frequencies to an insertion gain curve to give a specific coupler response. In addition to CORFIG it is necessary to take into account the effects of the sound bore of the hearing aid and the effect of adding a vent. That is:

\[ \text{REIG} = \text{Coupler Gain (CG)} - \text{CORFIG} + \text{sound bore effects} + \text{vent effects} \]

The correction factor, CORFIG, is made up of three components. First, head and ear diffraction effects will usually cause the input to the hearing aid to be larger in the real ear than in the undisturbed field. This difference is referred to as the Microphone Location Effect (MLE). Second, the equivalent residual volume of real ears medial to the earmold or shell is usually less than 2 cc, and therefore a higher sound pressure level (SPL) is generated in the real ear than in a coupler. This difference is called the Real Ear to Coupler Difference (RECD). Third, because REIG equals REAG minus Real Ear Unaided Gain (REUG), the hearing aid must first have enough gain to compensate for the loss of REUG when a hearing aid is worn. In total:

\[ \text{CORFIG} = \text{REUG} - \text{MLE} - \text{RECD} \]

If the hearing aid is to be fitted to an REAG target, rather than an REIG target, CORFIG is not relevant, as the REUG component of CORFIG plays no part in the measurement of REAG. REAG can be calculated from coupler gain as follows:

\[ \text{REAG} = \text{CG} + \text{MLE} + \text{RECD} \]

Although composite correction factors like CORFIG, or the sum of MLE plus RECD, are useful for predicting the gain of linear hearing aids, they are not suitable for non-linear hearing aids. The complication is that a change of signal level that occurs prior to a signal-processing non-linearity has a different effect than one that occurs subsequent to a non-linearity. Microphone location effects, for example, affect the level of sound going into a hearing aid whereas RECD affects the level of sound coming out of the hearing aid. To apply correction factors correctly to non-linear hearing aids we thus need to know the value of each component.

Although there is much published data on the various components, the values for MLE, REUG and RECD that should be used depend on the conditions under which the hearing aid is measured or used. For example, REUG depends on whether the sound field is diffuse or direct, and in the latter case, on the angle of incidence of the incoming sound. REUG will also be affected by the calibration method used. If the real ear gain analyzer uses a control, or reference, microphone positioned on the surface of the skull, this microphone will remove that portion of the REUG that is generated by the bulk of the head, rather than by the shielding, sound-gathering, and resonating effects of the pinna, concha, and ear canal. The REUG should therefore be smaller when a control microphone is used than when it is not used. The same considerations apply to microphone location effects: these will similarly be affected by the type and direction of field, and by the use of a control microphone.

Several other considerations apply to RECD. As the length of the canal stalk of the earmold or shell is increased, the residual volume will decrease, and RECD will increase, particularly
in the high frequencies. This will be true for any type of hearing aid. Canal stalks that extend past the second bend are, however, most commonly used in CIC hearing aids. As the mold or shell is made to have a tighter fit to the ear canal, leakage will decrease, and the RECD in the low frequencies will increase.

**Research question:** The aim of this study was to gather representative data on adults for Real Ear to Coupler Difference, Microphone Location Effects and Real Ear Unaided Gain, under a range of conditions that can be applied to clinical test situations.

**Procedures:** Subjects were ten male and eight female adults.

**Microphone Location Effects (MLEs):**
For each subject, ear impressions were carved to simulate CIC, ITC and ITE hearing aids. A small bridge of impression material was moulded on the outside surface of each impression so that a probe tube could be attached with the opening of the tube positioned where the hearing aid microphone would normally be situated. For BTE measurements a probe tube was inserted into a BTE hearing aid case with the opening of the tube at the opening for the hearing aid microphone. Measurements were made in an anechoic chamber at azimuths of 0 degrees and 45 degrees. To obtain diffuse field data, measurements were made in a reverberation room.

**Real Ear Unaided Gain (REUG):** REUG was calculated to be the SPL measured in the ear canal minus the SPL in the undisturbed field.

**Real Ear to Coupler Difference (RECD):** For each subject, one impression was sent to an earmould laboratory to be made into an earmould with standard 2mm sound tubing and a parallel bore for a probe tube. The RECD measurements have not yet been completed.

**CORFIG:** CORFIG will be calculated using the formula given above when data collection is complete.

**Findings:** Microphone Location Effects: MLEs at 45 degrees show the expected increase in high frequency boost as the size of the hearing aid decreases. There is however little difference between the MLE for an ITC versus a CIC. This is not surprising as the underlying diffraction effects are caused by the head and pinna. Both of these affect both types of hearing aid. It is not generally appreciated that the pronounced MLEs observed at high frequencies for ITC and CIC hearing aids are only obtained over a small range of azimuths. When the sound arrives from behind or from the far side, the head and pinna act as acoustic barriers, and the MLE can be expected to be negative. The diffuse field MLE represents the average (calculated on a power basis) of the MLE for sounds coming from all directions. The result (not shown) is a much smaller MLE than is applicable for frontal or near-side angles of incidence.

**REUG:** As with the MLE data, and for the same reason, the REUG for a diffuse field is much less than that for 0 or 45 degrees. Using a control microphone decreases the size of REUG from about 400 Hz upwards. The control microphone removes the diffraction effects due to the head while leaving in place those diffraction effects due to the pinna, concha, and ear canal.

**Significance:** The complete data from this study are being incorporated within the NAL-NL1 prescription software for non-linear hearing aids. They will enable anyone using the NAL-NL1 software to pre-adjust hearing aids as accurately as possible using average correction factors, and will thus minimise the need for adjustments of the hearing aid after real ear gain has been measured.

Fitting low ratio compression to people with severe and profound hearing losses

Investigators: Chris Barker, Harvey Dillon & Philip Newall*
*Macquarie University

Background: The usefulness of Wide Dynamic Range Compression (WDRC) for people with severe and profound losses has rarely been evaluated, despite the theoretical advantages to be expected from compressing a large input range into the restricted dynamic range of the severely or profoundly hearing impaired ear. For soft sounds, WDRC provides greater amplification than a linear aid (assuming both are matched in gain for moderate level input). For loud sounds, WDRC provides reduced amplification relative to a linear aid, theoretically providing an additional layer of protection against more intense input. However, these potential advantages of WDRC must be weighed against the heightened risk of acoustic feedback oscillation induced by the additional gain for soft sounds. In addition, not all soft sounds are desirable, and the raised level of ambient noise and aid microphone noise may be fatiguing. The reduction in gain for louder sounds may also be counterproductive if the aid user wants to hear higher level input loudly.

WDRC can be configured so that intense treble sounds are attenuated (TILL design), or so that intense low frequency sounds are attenuated (BILL design). In the Bernafon/NAL range of aids, a third possibility exists: frequency independent WDRC, in which neither bass nor treble input is especially favoured by the compressor. It was this last option that was the subject of this study.

Research questions: Can WDRC in the form of frequency independent, fast acting 2:1 AGCi provide long term benefits to adults with severe and profound hearing losses and, how does this compare with linear amplification?

Procedure: Sixteen severely and profoundly hearing impaired adults were fitted with hearing aids that had a combination of output controlled compression limiting and input controlled compression (AGCi) with a 2:1 compression ratio. Where the hearing aids had sufficient gain, the AGCi compressor was adjusted to have a low compression threshold (~70 dB SPL) in another program. Unfortunately, but not unexpectedly, feedback prevented the use of low threshold WDRC for half the subjects in the trial. However, higher level (~70 dB SPL) AGCi was possible for 13 subjects. Field trials of one to three months were conducted, comparing pairs of options: lower versus higher compression threshold 2:1 AGCi (8 Ss); higher compression threshold AGCi versus compression limited linear amplification (5 Ss); and, for the three subjects for whom no form of AGCi was achievable, compression limiting versus PC limiting.

Findings: In general, the less severe the loss, the greater the likelihood that low ratio low threshold, frequency independent 2:1 AGCi could be achieved while still maintaining adequate loudness for speech at an input level of 65 dB SPL. However, the most favoured option was 2:1 AGCi with a mean compression threshold around 70 dB SPL. Such a setting provides gain reduction for louder sounds but no additional gain for soft sounds relative to a linear aid. The findings were similar to our previous observations for mild to moderately impaired users of the same type of aid (Barker & Dillon, 1999).

Low ratio frequency independent compression reduced the need for manual control of volume (relative to linear amplification) for 12 of the 13 subjects who were able to try it. Subjective estimates of benefit were varied, but the general perception was that the addition of higher level 2:1 AGCi improved the acceptability of louder sounds and that this benefit was well regarded. Problems remained for all subjects in the area of soft speech amplification, but this was not considered a critical shortcoming.

Significance: This project has two important implications for clinical practice. When combined with our previous research, it suggests that low ratio compression should be the default amplification scheme for all hearing aid fittings, provided that adequate loudness can be achieved for moderate input levels.
The mechanisms of wind noise in hearing aids

(The research was partly supported by Danavox, Oticon, Phonak, Widex)

Investigators: Harvey Dillon, Inge Roe, Richard Katsch

Background: Acoustic noise generated in a hearing instrument, as wind flows past the microphone, is a problem encountered by hearing aid users. Understanding wind flow dynamics, in particular turbulence generation, around the head and ears is an essential step in reducing wind noise in hearing instruments. When a wind flows past an obstacle, such as a head or an ear, the wind has to change course to flow around the obstacle. This creates velocity differentials within the medium, and as particles with different velocities mix and attempt to slide past each other, shear stresses, and hence pressure differentials, are created because of the medium's viscosity. When the flow velocity becomes sufficiently high relative to the size of the obstacle, eddies form, usually at the point where the flow departs from the obstacle. The resulting variations in velocity with time and distance are referred to as turbulence.

Research Question: This study aimed to better understand the mechanism by which wind generates noise in a hearing aid. To achieve this, the study aimed to measure detailed wind profiles of flow and turbulence around a head and ear, and to quantify the amplitude and spectrum of acoustic noise generated at specific locations around the ear. These locations primarily comprised the places usually occupied by microphones in different types of hearing aids.

Procedures: The head of an acoustic manikin (KEMAR) was mounted in a smoke-filled wind tunnel 0.7 m high and 1.25 m wide. Velocity smooth flow and velocity turbulence were both measured with a Laser Doppler Velocimeter (LDV) focused on points in space near and within the ear. KEMAR directly faced the wind stream. The wind velocity was 5 m/s, which corresponds to a gentle breeze. Instantaneous readings of velocity (comprising x, y and z components) at a single location were combined to produce estimates of the mean three-dimensional velocity and the rms turbulent velocity at that location. Images of mean flow and turbulence around the ear were built up by combining such measurements at many different locations on a 10 mm square grid located 5 mm out from the surface of the pinna.

For acoustic noise measurements KEMAR was positioned within a smaller, specially quietened wind tunnel (NAL R&D Report, 1997/98). Noise was measured with miniature hearing aids microphones mounted in dummy hearing aids in typical hearing aid positions. Wind velocity was again 5 m/s.

Findings: Mean flow and turbulence around the head was greatly affected by the shape of the pinna. For frontally incident wind, the pinna caused the wind to locally diverge from the head surface. Immediately above the pinnae there was no divergence. As a result turbulence was greatest around the rim of the pinnae, close to the location at which Behind the Ear (BTE) hearing aid microphones are frequently placed. Acoustic measurements were consistent with these findings. Out of the locations typically occupied by hearing aid microphones the BTE location was by far the noisiest. A gentle breeze caused the SPL of the noise at the microphone...
inlet of approximately 95 dB SPL per 1/3 octave band around 400 Hz. The spectral shape of the noise was broad with a low-pass characteristic. The quietest of the locations was inside the ear canal, in the position usually occupied by a microphone in a completely-in-the-canal (CIC) hearing aid. Across frequency, noise levels here were 10 to 20 dB lower than at the BTE location. More detailed measurements of noise inside the concha indicated that turbulence at different locations were highly dependent on wind direction. The following principles were established.

- Turbulent noise is greatest immediately downstream of the trailing edge of an obstacle.
- Turbulence is least in locations that are centrally behind an obstacle.

If we consider the tragus as an obstacle, we can see that it can protect an in-the-canal hearing aid from wind noise for wind coming from one direction, but can act as a generator of intense wind noise when wind comes from another direction.

A surprising result was that most wind noise is generated by the head and pinna, rather than by the detailed shaped of the hearing aid.

**Significance:** The study gives us a much clearer understanding of how wind generates noise in hearing aids. Future work will investigate solutions that minimize the extent of noise picked up.
Is the clinical paired comparison test for hearing aid evaluation a useful and reliable tool for optimising amplification for severely/profoundly hearing-impaired children?

Investigators: Teresa Ching, Mandy Hill, Greg Birtles*
* Currently Macquarie University

Background: The provision of effective amplification is vital to the development of speech and language of hearing impaired children. To achieve this, hearing aid selection must be guided by a prescription that has been validated to be best for speech intelligibility, such as the NAL-RP procedure (Byrne & Dillon, 1986; Byrne, Parkinson, & Newall, 1991). Subsequent to the initial fitting, evaluation of the fitting is essential to ensure that amplification characteristics are optimised for the individual. This is because amplification requirements are not fully predictable from the audiogram. The prescription formula calculates average requirements based on hearing thresholds, and there will always be a small proportion of individuals who will be better fitted with either more or less gain or more or less low or high frequency amplification than the prescription.

We have developed a clinical procedure that makes use of a paired comparison test to evaluate hearing aid frequency responses for children over six years of age (Ching, et al., 1999). This procedure aims to determine whether there is an alternative frequency response that is better than the NAL-RP prescription for speech intelligibility for an individual child. It is adapted from the clinical evaluation procedure for adults (Byrne, 1987). During the evaluation, the child wears a programmable hearing aid, and frequency response options are loaded temporarily onto a hearing aid via a programming unit connected to a computer. A recorded story is presented audio-visually, and the child is required to compare speech amplified using the NAL-RP prescription with speech amplified using variations from the prescription that either provides more or less gain at the low or high frequencies. The child switches from one frequency response to another while listening to the story, and chooses the one that makes the story easiest to understand.

Research questions: This project aims to examine the following questions: 1) Are the amplification characteristics selected in the clinical paired comparison test optimal for real life situations? 2) Do children's judgments in paired comparison tests vary from one test to another? 3) Do clinical and educational audiologists find the test convenient to use and helpful for improving fitting outcomes?

Procedure: Twenty-two children with severe/profound hearing losses (34 ears) were tested using the clinical paired comparison procedure. To address the first question, a sub-group wore hearing aids set to the NAL-RP prescription, and to two other alternative frequency responses that provided either more low or less low frequencies than the prescription at different time intervals. Their phoneme identification ability was recorded on a daily basis. The parents and teachers of the children were also interviewed regularly regarding their observations of the children's aural/oral performance in everyday situations and in educational settings respectively. To address the second question, a different sub-group was tested a second time within a month of the first test. To address the third question, we solicited feedback from clinical audiologists and educational audiologists who have used the procedure in their own clinics.

Findings: The clinical evaluation results indicate that the NAL-RP prescription was close to optimal for most children tested, and provided a good starting estimate of the gain-frequency response needed by the individual. Only one child among the 22 children tested found a frequency response with more low frequency emphasis than the prescription to be...
better for speech intelligibility. Children amplified using the frequency response selected at the paired comparison test during home trials were also rated to be performing better in everyday life situations and in speech tests than when they were amplified using an alternative setting.

The clinical paired comparison test demonstrates good repeatability. All children who were retested chose the same characteristics in the second test as they did in the first. Feedback from clinical and educational audiologists indicates that the procedure is easy to use, and is effective in improving fitting outcomes in two ways. Firstly, audiologists felt that the procedure was useful for verifying whether the prescription was optimal for the individual child, and if not, for indicating how a fitting needed to be modified. Secondly, it was useful in demonstrating to parents that hearing aids were fitted to suit the individual needs of their children. On average, the paired comparison test could be completed in 21 minutes for each ear.

**Significance:** We can optimise hearing aid amplification characteristics for individual severely/profoundly hearing impaired children by using a clinical procedure based on paired comparison judgment of speech intelligibility. This method is easy and practical to use in a clinic, and has been found to have good repeatability and validity for listening in real-life situations.

---

**References**


**Fitting hearing aids to children who also use cochlear implants**

(This project is funded by the CRC for Cochlear Implant, Speech and Hearing Research)

**Investigators:** Teresa Ching, Colleen Psarros¹, Mandy Hill and Harvey Dillon

¹Children’s Cochlear Implant Centre

**Background:** An increasing number of hearing impaired children who use a cochlear implant in one ear have useable residual hearing in the opposite ear. It is vital that this ear receives auditory stimulation to help preserve the hearing capability, and a non-invasive option is to fit a hearing aid to the ear. There is also some evidence that speech recognition may be improved when a cochlear implant is used with a hearing aid rather than used alone (Shallop et al., 1992; Blamey, et al., 1997).

For children who also use cochlear implants, there are at least two reasons why their hearing aids may need to be adjusted differently to those who wear hearing aids in both ears. Firstly, the growth of loudness arising from electrical stimulation and acoustic stimulation could be different. Secondly, the ear amplified with a hearing aid may be more efficient at extracting low rather than high frequency information from an acoustic signal, whereas the ear with a cochlear implant may be better at transmitting high frequency information than with a hearing aid. For overall auditory
perception, it may be most effective to provide information to each ear in the frequency range that it can analyse most effectively.

**Research questions:** (1) Do children require hearing aid frequency responses that differ from the NAL-RP prescription when they use hearing aids with cochlear implants? (2) Do children require hearing aid gain that differs from the NAL prescription? (3) Can children recognise speech better when they use hearing aids with cochlear implants than when they use cochlear implants alone?

**Procedure:** We have devised a procedure to adjust a hearing aid to achieve balanced loudness between the ear that is aided by a hearing aid and that by a cochlear implant for each child. The result of the procedure is hearing aid gain and frequency response characteristics that amplify sounds so that they are equally loud in both ears, and this is often slightly different from the NAL-RP prescription for the child. Seven children were asked to compare gain-frequency responses determined in this way with the NAL-RP prescriptions, and also with some variations from the prescription that provided either more or less low or high frequencies. In the test, each frequency response was compared with every other frequency response in a random order. In each trial, the child compared a recorded story amplified using two alternatives, and chose the one that made the story easiest to understand. This was designated the optimal hearing aid gain-frequency response for speech intelligibility for the child.

The children were also tested with BKB sentences and nonsense syllables when using cochlear implant alone, hearing aid alone, and when they used cochlear implants with hearing aids.

**Findings:** Preliminary results (Ching, Psarros, Hill, 1999) indicate that children preferred slightly more low frequency emphasis, and more overall gain than that prescribed by NAL-RP when using their hearing aids with cochlear implants. They also performed better in speech tests when using both devices together than when they used each device on its own.

The first figure shows the preferred frequency response slope in terms of dB/octave from 500 to 2000 Hz compared to the NAL-RP prescribed slope. The diagonal line indicates complete agreement between prescribed and preferred slope. Six out of the seven children preferred more low frequency emphasis than the prescription. The variation is within 6 dB/octave.

The second figure shows the preferred gain averaged over 500, 1000 and 2000 Hz compared to the NAL-RP prescribed gain. All children preferred more overall gain than the NAL-RP prescription when they used hearing aids with cochlear implants. The required three-frequency-average gain ranges from 3 to 12 dB more than the prescribed gain.

The third figure shows the mean speech test scores. The left panel shows BKB sentence scores and the right panel shows nonsense syllable scores. Results for 4 amplification conditions are shown: when the children used cochlear implants with hearing aids on current user setting before adjustment (CUA), hearing aids alone (HA), cochlear implants alone (CI), and the NAL-RP prescribed gain.

**Six out of the seven children preferred more low frequency emphasis than the prescription.**
and cochlear implants with hearing aids on optimal setting (COA). The solid line represents speech scores in quiet, and the broken line shows speech scores in babble noise at a signal-to-noise ratio of 10 dB. On average, children performed better when using cochlear implants and hearing aids together than when they used a single device on its own.

**Significance:** The results from this study will be applied to guide hearing aid fitting for people who use hearing aids with cochlear implants. The information will also be used to help formulate management programs for hearing impaired children, and to counsel parents and children regarding the benefits of amplification in both ears.

**References:**


**The effects of sound field classroom amplification on the communicative interactions of Aboriginal and Torres Strait Islander children**

**Investigators:** Robyn Massie, Denis Byrne, Deborah Theodorus¹, Brad McPherson², Joseph Smaldino³

¹ University of Queensland
² University of Hong Kong
³ University of Northern Iowa

**Background:** Aboriginal and Torres Strait Islander (ATSI) children suffer from long term middle ear disease and resultant hearing loss from an early age. Evidence suggests that communication abilities are compromised (Bench & Harrold, 1996). Australian studies have indicated that 50 percent to 80 percent of indigenous school students have sufficient hearing impairment to adversely affect classroom performance (Nienhuys, 1994). In addition to hearing problems, the listening environment of the typical classroom makes it difficult to understand spoken instruction. A major problem is that background noise levels tend to be similar throughout the room, but the teacher’s voice becomes weaker as the distance between the teacher and child increases. The teacher’s voice may be so poor at the child’s ear that the speech is masked by the noise, a term known as the signal to noise ratio (S/N ratio). Communication difficulties are further exacerbated because ATSI children usually have non-indigenous teachers who bring differences in language, expectations and interpretations to the Westernised school setting (Lowell, 1995). Furthermore, ATSI children have a cultural preference for different learning styles, a factor which may contribute to their poor school achievement (Harris, 1990).

Sound field classroom amplification is a relatively new approach to hearing habilitation in Australia. Previous R&D reports have described the NAL designed system. The system provides up to 10 dB amplification to the whole classroom, but without making sounds too loud for normal hearing children (Crandell, Flexer & Smaldino, 1995). Currently there are over 400 sound field FM amplification systems being utilised around Australia, many in the...
Acoustic measurements for each classroom

<table>
<thead>
<tr>
<th>Classroom</th>
<th>Mean Noise Levels (occupied)</th>
<th>Mean Reverbartion Time (unoccupied)</th>
<th>Mean S/N ratio (amplified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom 1</td>
<td>62dBA</td>
<td>1.8 seconds</td>
<td>+3dB</td>
</tr>
<tr>
<td>Classroom 2</td>
<td>67dBA</td>
<td>1.3 seconds</td>
<td>+2dB</td>
</tr>
<tr>
<td>Classroom 3</td>
<td>72dBA</td>
<td>1.7 seconds</td>
<td>+1dB</td>
</tr>
<tr>
<td>Classroom 4</td>
<td>75dBA</td>
<td>1.8 seconds</td>
<td>–5dB</td>
</tr>
</tbody>
</table>

classrooms of ATSI school children. Whilst anecdotal evidence suggests benefits, the purpose of the study was to provide an objective evaluation of the systems in Australia.

**Research Questions:**
1. What is the hearing status of a target population of school children?
2. What are the acoustic characteristics of the classrooms and what levels of amplification are produced in the field?
3. What are the effects of classroom amplification intervention on the communicative interactions of Aboriginal and Torres Strait Islander school children?

**Research procedures:** An eight week field trial of sound field amplification was trialed in four classrooms, two in each of the rural communities of Cherbourg and Yarrabah. The listening environments of the classrooms were alternated between amplified and non-amplified conditions at two weekly intervals. Hearing tests were carried out on the 64 children. Acoustic measurements, including ambient noise levels, reverberation times and signal to noise ratios, were obtained for each classroom. A pilot modified Environmental Communication Profile developed by Calvert and Murray (1985), was used by trained observers to record the communicative interactions occurring between the child, teacher and peers simultaneously. Information was obtained on (i) the type of communication e.g., verbal or non-verbal, (ii) the direction of the child’s communication, and (iii) who cued the child’s communication.

**Findings:**
1. The mean pure tone average hearing level for this paediatric population, calculated as the average of the thresholds at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz in the better ear, was 20.0 dBHL pre-trials and 18.7 dBHL post-trials. These levels fall into the category of slight hearing loss as defined by (Clark, 1981).
2. Each of the classrooms demonstrated extremely noisy listening conditions (see Table above). Ambient noise levels and reverberation times were very high relative to recommended levels. All the mean S/N ratios were in the minus range under normal listening conditions. Amplified, the effect of the systems across classrooms ranged from +4 dB to +10 dB.
3. Comparison of observational data obtained during the first ‘ON’ listening phase with the second ‘ON’ listening phase for all classrooms revealed the following changes over time:
   - A significant increase in the number of communicative interactions occurring between the teacher, child and peers.
   - A significant increase in verbal communication between the teacher, child and peer over time
   - A significant decrease in non-attending behaviours by the child.
   - A significant increase in the child’s communication in response to cues directed to the class as a whole from the teacher or a peer.
   - A significant increase in the child’s communication in response to direct cues from the teacher or peer.
   - A significant increase in the child’s communication in response to the teacher addressing a peer.

**Significance:** The results confirmed the extremely noisy listening environments in which the teachers and children are operating on a daily basis and emphasised the urgent need for classroom acoustics treatment in conjunction with sound field amplification installation.

The enhanced listening environment had the effect of increasing the communicative interactions occurring in the classroom, and
produced changes in the dynamics of classroom communication. In particular, the use of verbal communication between the child, teacher and peers increased. As teacher or peer behaviour was only recorded when it cued the child's communication, the results confirmed the child's increased preference to verbally communicate with the teacher and/or peer. This increased attentiveness to verbal cues may indicate less difficulty learning through 'teacher talk', and increased ability to utilise the verbal teacher-oriented learning behaviours associated with success in a Westernised school setting. There was also less reliance or non-attending behaviours by the child. The effect of this was to reduce the restlessness and aimless chatter noted to occur in typical ATSI classrooms (Kearins, 1985), rendering the classrooms less noisy.

The child was taking a more proactive role in classroom communication, as indicated by the increased response to cues directed to the class as a whole, as well as to cues directed to a peer from the teacher. These findings suggested an improvement in self confidence which was also reflected in the way the child was communicating verbally more with his/her teacher or peers. As three of the four classrooms were experiencing new teachers, this was an important result. The results may also indicate that the language differences found to be a major barrier to effective classroom participation in cross cultural educational settings were reduced.

Although less than optimal S/N ratios were achieved, reducing the effects of slight hearing impairment under adverse listening conditions may alleviate the communication problems arising from the complex interaction of culture, language, hearing loss and poor listening environment operating in the classrooms of ATSI children.

References:
A major objective of NAL research is to increase understanding of the harmful effects of noise on people and to contribute to the prevention of hearing loss. NAL research that addresses these objectives is described in the following two sections.

Hearing loss prevention research has been using otoacoustic emission testing over several years. The three projects to be described concern improving methodology for measuring and interpreting otoacoustic emissions and using such data to assess the individual risk of noise-induced hearing loss and for modelling ear damage.

The second section reports four noise measurement studies covering the varied areas of traffic noise, aircraft noise, and the occupational “noise” exposure encountered by orchestral musicians.
Longitudinal Study of a non-noise exposed cohort comparing click-evoked otoacoustic emission techniques and pure tone audiometry

**Investigators:** Narelle Murray and Eric LePage

**Background:** Since the introduction of the click-evoked otoacoustic emission technique in Hearing Loss Prevention in 1989, the investigators have been conducting two longitudinal studies involving (a) an essentially non-noise exposed population - staff members of Australian Hearing, and, (b) a moderately noise-exposed population - instrumentalists from the Australian Opera and Ballet Orchestra (AOBO). Reports have been made previously into some aspects of the AOBO study (Murray, LePage & Mikl, 1998). This report is an assessment of some of the results from the cohort study of non-noise exposed individuals.

**Research Question:** The research question for both studies has remained the same. That is, if by objectively assessing the hearing status of individuals by click-evoked otoacoustic emission testing, and comparing the results with subjective testing of hearing thresholds with pure tone audiometry, can we establish usable parameters to monitor the hearing status of this cohort over a period of up to 7 years.

**Procedures:** At approximately yearly intervals subjects have been tested with both pure tone audiometry and click-evoked otoacoustic emissions. Pure tone audiometric thresholds were established for each of the frequencies 0.5, 1, 2, 4, 6 and 8 kHz. Click-evoked otoacoustic emissions were measured using the Otodynamics ILO 88 Analyser. Two hundred and sixty responses from each ear were averaged at a constant “nonlinear” stimulus level of 80 (±1.5 dB) peak SPL. The minimum acceptable stability of recording was set at 80%. At each visit subjects completed a detailed questionnaire which assessed their past and present aural health and other factors which have previously been associated with hearing loss, e.g. tinnitus, antibiotic and anti-inflammatory use, smoking and recreational noise exposure. Because of the nature of a longitudinal study, some subjects dropped out because of change of employment, while others were unavailable for testing in certain years. Only those subjects who had a minimum of two test sessions, and, if only two,
those sessions at least two years apart, have been selected in any analysis of the Cohort. This accounts for the gaps in the data for some years. Out of a total of 47 subjects tested over the period of the study thus far, analysis has been undertaken on 24 males and 8 females.

In considering the data statistical analysis was undertaken on three parameters: Otoacoustic emission (OAE) Waverepro%, OAE Coherent Emission Strength (CES dB SPL) and Pure Tone Audiometry (PTA). As the study is longitudinal, interest has been focussed on changes which have occurred in all parameters during the life of the study. Results for each of the OAE parameters were calculated on the basis of (a) all frequency bands (referred to as Broadband), (b) frequencies >2000 Hz (Hipass) and, (c) frequencies <2000 Hz (Lopass). The most appropriate PTA comparisons with these OAE frequency bands were felt to be the mean of 1,2,4 kHz, 6 kHz and the mean of 0.5,1.2 kHz respectively.

Findings: The results of ANOVA for each of the three parameters of both Waverepro% and CES showed no significant variations between years for either left or right ears (p<0.05). Similarly, ANOVA for the three PTA frequency bands selected showed no differences either between ears or between years (p<0.05). The two figures opposite left show results for each ear and each year for CES and PTA respectively. It does appear that, despite there being so little change in any of the parameters measured, CES does identify more ears with significant changes over time (figure below). CES also appears to identify many more ears with low emissions which still have pure tone thresholds within normal limits. (Murray, N., LePage, L. & Tran.K, 1997; Murray, N., 1999) CES would, therefore, seem to be a better early warning indicator than PTA of those ears which are more vulnerable to early ear damage.

Although there is little change over time in overall group data, there are wide variations in results, with “improvements” as well as declines being observed in both OAE and PTA results. While any “improvement” may be deemed a learning process in the test-retest situation of the subjective pure tone audiometric testing, this could not be applied to the results of otoacoustic emission testing. However, it is possible that these widely variant, almost random, results may be consistent with a system which is nonlinear and not at all well ordered. Gold (1989) first predicted this disorder and indeed, Shera and Zweig (1993) and Wit et al.
An example of binaural 'see-saw' where the trend in the left ear is downward for both hipass and lopass CES while the trend in the right ear is upward for these parameters.

Significance: Analysis of high and low frequency components of both emissions and pure tone thresholds has enabled us to look more closely at the suggestion of LePage (1992) of the possibility of "permanent re-mapping of the cochlear partition in the case of OHC loss, thereby transferring the frequency representation away from regions in which there is OHC loss to regions where OHC remain". This is the most likely explanation for the monaural 'see-saw' effect. Otoacoustic emissions has allowed non-invasive investigation of this phenomenon in the human cochlea.

References:
Hearing Status of Aboriginal Prisoners

**Investigators:** Eric LePage, Narelle Murray, Tony Butler*
* NSW Department of Health

**Background:** The NSW Department of Health extended an invitation to NAL Hearing Loss Prevention Research to participate in their very extensive health study of men and women in NSW Correctional Centres by way of hearing assessment using click-evoked otoacoustic emissions.

**Research Question:** To investigate whether the hearing of prisoners differed in any way from that of our predetermined normative Australian population. Because of the quite large population of Aboriginal and Torres Strait Island (ATSI) prisoners it was of particular interest to see if their hearing status differed a) from other prisoners and b) from the normative Australian population.

**Procedures:** Training was provided for the nurses in the Department of Corrective Services who were involved in the total study to carry out our standard clinical procedures for otoscopic examination and recording click-evoked otoacoustic emissions. All subjects completed a brief questionnaire which included questions relating to hereditary hearing loss, aural pathology, hearing aids, tinnitus, occupational noise, listening to loud music and head injury. Data were collected on 705 male and 122 female ears. Of these, there were 251 male and 24 female Aboriginal ears. The Analysis presented here was carried out on prisoners aged between 20 and 60 years which resulted in 675 male ears (251 Aboriginal) and 114 female ears (24 Aboriginal). The NSW Department of Health provided a breakdown of the numbers of Aboriginal and non-Aboriginal prisoners, together with other basic demographic data. Comparisons were carried out using the derived single number index Coherent Emission Strength (CES dB SPL) (LePage & Murray, 1993).

**Findings:** The first figure shows the result of a Multiple Regression Analysis carried out on the total data. For the age groups in question this can be interpreted that Aboriginals are more at risk of hearing impairment than non-Aboriginals, prisoners more at risk than non-

---

**Results of multiple regression on all 3074 subjects aged between 20 and 60 years (n=3074 ears) showing the difference in CES values between males and females, prisoners and non-prisoners, Aboriginals and non-Aboriginals and between age groups one decade apart. The differences are those indicated by the regression coefficient.**

![Graph showing CES values between different groups](image-url)

**Mean (±1 SD) Coherent Emission Strengths comparing all Normative male ears - solid squares (n=1189) with Aboriginal male prisoners - open circles (n=251 ears) and non-Aboriginal male prisoners - open triangles (n=452 ears) for ages between 20 and 60 years.**

Mean (±1 SD) Coherent Emission Strengths comparing all Normative female ears - solid squares (n=979) with Aboriginal female prisoners - open circles (n=24 ears) and non-Aboriginal female prisoners - open triangles (n=98 ears) for ages between 20 and 60 years.
prisoners and that males are more at risk than females. The second and third figures show the variations which occur between our predetermined male and female normative population for each of the four age decades under discussion and male and female Aboriginal and non-Aboriginal prisoners in those same age groups. It is not possible to determine from this study whether any hearing loss in the Aboriginal prisoners is of a sensorineural or conductive nature. Low emission strength can be indicative of a conductive hearing problem as well as a sensorineural hearing problem and tympanometry which would have elucidated this was not carried out. However, with the exception of the oldest age group where the numbers in each case are not significant, it can be seen there is a steady decline in ear damage from the normative groups through the non-Aboriginal prisoners to the Aboriginal prisoners. From the questionnaires it also appears that Aboriginals are more likely to suffer head injuries and, although not of significant difference, those with head injuries, in the main, have lower emission levels than either those Aboriginals or non-Aboriginals with no head injuries. This may have an important bearing on the lower emission levels in general of Aboriginals in custody.

Significance: It has been well known for some time that the hearing of Aboriginal children is affected by chronic otitis media leading to conductive hearing losses. It has been assumed that there would be some legacy of this childhood affliction into adulthood. Our data shows that this is quite likely and that ear functionality as assessed by otoacoustic emissions in adult Aboriginals is poorer than that of the rest of the population. It would appear that hearing health care programs aimed at helping Aboriginal children would need to be continued into their adulthood.


Modelling transient evoked otoacoustic emissions in noise-induced hearing loss

Investigators: Eric LePage and Åke Olofsson*

*Unit of Technical Audiology, Department of Ear and Skin, Karolinska Institute, Stockholm, Sweden.

Background: Evoked Otoacoustic Emissions (EOAE) have opened up the field of audiology to provide a significant increase in the amount of diagnostic information. To limit its clinical application to determinations of emissions “present” or “absent”, or test “pass” or “fail” for any particular client is merely to utilise a tiny fraction of the available information. The technique instead has enormous potential in evaluating firstly, the effects of noise exposure, both in the workplace and that due to leisure noise, and secondly, the state of function of the binaural processing of sound and the role of descending pathways. Many investigations have sought to understand the relationship between audiometric thresholds and emission spectra. At NAL we have shown that EOAEs complement the audiogram, providing a measure of outer hair cell motor performance which anticipates changes in the audiogram (LePage and Murray, 1993). This means that EOAEs also have the potential to offer new precision in the fitting of hearing aids, particularly in cases of uncertainty. There exist two main types of EOAE test, transient evoked emissions (TEOAE) and distortion product emissions (DPOAE). Distortion products have the advantage that they are generally carried out at audiometric frequencies mostly only up to 8 kHz. The transient approach delivers the information as a spectrum across a range of frequencies. In young individuals this range extends to above 4 kHz, but in adult males emissions are present mostly only below 2 kHz. This presents a puzzle for audiologists because such people may be hearing frequencies which can still extend well above 4 kHz. Evidently the transient method is not so easily correlated with the audiogram.

Our data shows... that ear functionality as assessed by otoacoustic emissions in adult Aboriginals is poorer than that of the rest of the population.
many of these are from repeat measurements on the same people, over a ten year period. From observations of their emission spectra we have concluded that, just as the frequency range of normal sensitivities for the audiogram reduces over years, the bandwidth of the emissions steadily reduces, but earlier. This progressive reduction in bandwidth is directly related to the ski-slope feature in audiograms of aging ears and it is clear that OAEs can tell us much about the origin of the aging process in humans. Australian Bureau of Statistics data shows that our population is living to a greater age. Since many of our youth are showing prematurely low emissions, this suggests our ears can age relatively much faster than the rest of the body. Taken together, the differential between chronological age and ear age would appear to be increasing. Our research is therefore directed at extending our declining lifetime of normal hearing with all the attendant costs. Part of effective hearing loss prevention must be tied to education. The other major component has to be the availability of early warning. Our research suggests that OAEs have the potential to provide early warning by utilizing the concept of “ear age” thereby bypassing all the complexities of communicating hearing awareness for the average young person prone to the damage due to noise exposure. It would be very useful in promoting hearing loss prevention to be able to say, “You may be 25 years old, but your ears are responding as if they are 45 years old”. However, as things stand at present we have no simple error free way to measure the lifetime of normal hearing but we are making progress. We need to be able to refine our measures of OAE response to take into account normal aging (the process leading to presbycusis), gender, and changes which take place in the ear which are not immediately transparent from observing audiograms. The emission responses change with time which are not a simple decline across all frequencies. The first figure shows the right ear of a male subject measured over an 8 year span. The series of six records, shows not just a general decline in the size of the emission. The size and shape of the time waveform is systematically changing, resulting in subtle changes in the shape of the emission cross-power spectrum. Examining the records shows that the relative heights of the main peaks are changing, while other areas drop out completely and then return. The result illustrates the significant problem of deciding how much are changes due to measurement error or to the presence of noise on the emission signal, and how much is due to a real aging effect upon the ear. Secondly, are the changes in the peaks of the spectrum indicative of changes in the decline in outer hair cells? If so, do the changes represent a map of the degradation? Whereas the early OAE literature reported how click emission waveforms are like a “fingerprint” for an ear, our data show that over time, as one would expect with progressive loss of OHC throughout life, the reproducibility over time degrades. It is clear therefore that to make better use of the OAE information we need to understand what are the underlying changes which bring about changes in the appearance of the transient emission.

There are several approaches to this. One is to collect data over a long period (see our accompanying longitudinal study [Murray, et al]) and look for patterns which are common to very many people e.g. those with similar backgrounds or noise exposure profiles. The subsequent recognition of patterns may, however, provide little insight as to actual hair cell pathology. Another is to obtain otoacoustic emissions in live animal ears and correlate the cochlear histology post-mortem with previously measured emissions such as in the second.
Our research monitoring emissions in the same people over the past decade has shone light on the nature of the aging process...

Rare insight into aging in the human cochlea: a postmortem determination of hair cell counts (inner hair cells IHC and three rows of OHC) in a patient aged 72 years who had had some noise exposure during his life (Re-drawn from Hawkins et al, 1976).

...called from M atlab(tm). The result is a computationally efficient, flexible modeling environment which runs under Windows and which offers advanced displays of model properties.

For simplicity the first implementation models the OHC interaction as a scalar variable (rohc) which varies from 0 to 1 representing the fraction of OHC functionality from a dead cell to a fully active cell, so that lesions may be modelled as changes in rohc from one segment to the next, representing the long term effects of cochlear aging or noise exposure which make it applicable to the clinical research into prevention through early warning. The model is described as a wavefilter model made up of 350 segments, representing a 35 mm long basilar membrane. Each segment represents the combined activity of 0.1 mm or about 30 OHC. Sound "enters" the cochlea model by simulating a pressure waveform at segment 1. This progressively stimulates OHC activity as waves pass down the whole length of the cochlear and returning to the stapes, the reverse waves interacting with the forward waves at each point. The model is quite realistic in that OHC activity boosts the BM at each segment. While any stimulus type can be used, several parameters of the model can be measured at each segment (viz. displacement, velocity, pressure, even neural excitation). Most importantly the pressure wave applied to segment 1 is by definition the sound stimulus passing through the middle ear while the superimposed activity, which results from the OHC response, is the otoacoustic emission. If two tones are presented, a family of distortion products are produced by the model. Likewise by delivering a click sound stimulus the result is a realistic looking transient OAEs. (third figure). The beauty of the model is that just as a clinical otoacoustic emission is the result of signal averaging, such signal averaging can be applied to the model with the same procedures used in the clinic and the results may be analysed, complete with stimulus artifact removed, and presented in exactly the same way.

Results: Not unexpectedly, the presence of such lesions changes the frequency spectrum of the emissions significantly. The prime object of the current exercise is to observe what effect changing the position and length of single point lesions has upon the click emission spectrum. In recent times we have been utilising the short-term Fourier transform to produce time-
frequency plots of transient emissions. This particular representation allows the appreciation of both domains in the one figure. The output of the model is shown in the fourth figure. The three panels show the time-frequency representations of two lesions—one longer than the other by 50 segments, while the lowest panel shows the difference. It has been found that by changing the size of the lesions, there is a peak in the frequency response which appears to become accentuated and is actually tied in its frequency to the apical end of the lesion not the basal end (see fifth figure). The insight obtained in this way suggests that peaks in the TEOAE are due to sudden impedance changes in the cochlear partition which occur at the far end (distal to the stapes).

The computer model result seen in the fourth figure has been seen frequently in human OAE data without any definitive explanation. In the light of the model it can be suggested that the shifting peaks which are frequently seen and the resulting “light-dark” pigeon pairs which result in the difference plots, from one year to the next, have their origins in an increase in the size of damaged regions in their cochleas. It thus appears that following the approach which pairs real TEOAE data with model results may assist us in defining how far the idea of this type of result can be interpreted as a measure of physical damage which results from a particular kind of noise exposure.

**Conclusion:** In this our first application of the model artificial lesions of poorly functioning OHC are simulated and it has been found that for fixed length lesions, there is a peak in the spectrum which follows the map built into the model. In the case of variable length lesions the spectrum of the emissions exhibits a peak whose frequency varies systematically with the physical location of the apical end of the lesion with a small cumulative error. While such insight may be subject to the assumptions of the model, it was obtained with considerably less resources and ethical considerations than required to run a research program correlating hair cell cytocochleograms with OAEs.

**Significance:** Our research monitoring emissions in the same people over the past decade shone light on the nature of the aging process and that has led to the need to confirm our descriptive model using a computational model. While such models are most typically Simulated TEOAE for the standard non-linear stimulus paradigm for an ear with noise-type damage in which a loud pure tone has damaged the function of OHC over a short length (ca. 2 mm) of the cochlear partition. Remarkably, even a tiny change in rohc 0.8 to 0.75 produces a useful effect.

Time-frequency representations showing the time course upward of the frequency components of the emission. Two conditions of the model are shown, one with a 20 segment lesion at segment 150 and another instead at segment 200. The peak in the response is due to the presence of the apical edge of the lesion. The lowest panel shows the difference.
used to understand the normal cochlea, this is an application to the damaged cochlea and has provided insight as to how noise likely affects the ear for the first set of assumptions made. Such insight has never previously been available from human data. An extension of the idea that emission can help determine the rate of physical degradation in the cochlea is that the approach may be useful in defining the growth of cochlear lesions due to noise or aging. Further investigation of the model in conjunction with our patient data may promote real effectiveness in prevention strategies by definitive descriptions of OHC degradation. Using the model may thus lead to a strategy for defining the effective age of any ear. In turn this may lead to a better determination of the effectiveness of hearing protection devices.

References
Noise Investigations

Noise exposure reduction for musicians

Investigators: Warwick Williams, John Presbury¹, Carl Neilsen and Nick Williams²
¹ Australian Broadcasting Commission
² University of Technology, Sydney

Brief Report: This is a combined project between Symphony Australia, the ABC, the University of Technology, Sydney (UTS) and the National Acoustic Laboratories. The aesthetic and material design aspects have been carried out by UTS, acoustical considerations in the design and construction has been supplied by NAL along with the objective acoustic testing. The ABC, being the major shareholder of Symphony Australia, has supplied access to various symphony orchestras around Australia where subjective testing is being carried out on the acoustic performance of the “protective screens”.

Objective acoustical tests have been carried out in the medium anechoic room and during orchestral performances and rehearsals. Acoustically the “screens” perform well, with the objective tests showing that the screens can attenuate noise exposure by around 8 dB.

The subjective testing is being carried out in conjunction with what could be termed “cultural acceptance” testing. This is necessary because when a new procedure is introduced into a working environment such as a symphony orchestra there can be no guarantee that such a procedure will be accepted by the musicians. Hence, some trial time is required for the musicians to accept the use of the “protective screens”. As there is no time limit this testing will continue as required.

Several other organisations including the Australian Opera and Ballet Orchestra and the RAAF have expressed interest in trialing these devices.

Warringah Council - NSW WorkCover Authority project

Investigators: Warwick Williams, Michael Costello¹, Mary Leung² and Bob Cook
¹ NSW WorkCover Authority
² Warringah Council

Brief Report: During 1998/99 NAL became involved with a project “Local government occupational noise management implementation strategy” sponsored by the New South Wales WorkCover Authority in conjunction with Warringah Council. The main objective of the project is to reduce the incidence of hearing loss claims lodged by local government workers.

The project commenced with the intention of simply developing a “noise training program” that would raise the awareness of local government workers to the problems of noise exposure and various strategies that they could adopt in order to minimise their exposure. This should then have the effect of acting in a preventive manner such as to reduce noise exposure, reduce noise injury and the incidence of hearing loss and hence the number of hearing loss claims.

However, after initial consultations, focus groups and a “training” session with some of the Warringah Council employees, both WorkCover and NAL decided that the current project was not an appropriate course of action. Accordingly a new strategy is being followed adopting a more encompassing approach in which the main focus of training “workshops” will concentrate on the identification and treatment of all OHS hazards in the workplace. Noise exposure will be one of the example hazards selected to illustrate procedures.

The overall objective has now become one of helping the employees realise that they can develop their own workplace solutions to OHS problems and thus accept a share of the responsibility for OHS in the workplace along with management and employers.

The overall objective has now become one of helping the employees realise that they can develop their own workplace solutions to OHS problems and thus accept a share of the responsibility for OHS in the workplace along with management and employers. This concept fits well with the approach of the NSW WorkCover Authority.
Sydney Airport Health Study

Investigators:
Peter Peploe with Norman L. Carter, R.F.S. Job, S. Morell and R. Taylor (Sydney University)

Brief Report: It has been suspected for some time that aircraft noise may affect human health. It is known also that a change in noise environment leads to a disproportionate change in reaction to the new noise level. The aims of the present study are to determine if changes in aircraft noise level had specific effects on the health of people exposed to the noise.

Phase 1 of the study has been completed. This consisted of a study of mental health in adults and a study of the blood pressure of children aged 6 – 7 years, for the period before full implementation of parallel runway operations at Sydney Kingsford-Smith Airport. In conjunction with these studies detailed aircraft noise exposure data have been provided. More details of Phase 1 of the study and findings can be found in the 1995/96 and 1996/97 Research and Development Annual Reports.

Phase 2, examination of the effects of change in noise level, has commenced. The follow-up blood pressure measurements of children have been completed and matched with aircraft noise exposures. The mental health study is not yet complete.

Traffic Noise Sleep Study

Investigators:
Peter Peploe and Robert Cook (NAL), Norman L. Carter (Sydney University), Ron Grunstein (RPAH), David Joffe (RNSH), Delwyn Bartlett (St. Vincents Hospital), Anthony Williams (Neracrest)

Brief Report: This project has been funded by the Roads and Traffic Authority (RTA) of N SW. Its aim is to examine the effects of traffic noise on sleep and a person’s ability to perform set tasks.

In this study, 10 volunteer couples have been chosen to participate. Over a three-week test period, each subject pair has been exposed to recorded traffic noise and required to perform a series of tasks designed to indicate any effects of sleep disturbance. For half of the subject pairs, the test period consisted of exposure to recorded traffic noise in the first week on Monday to Thursday nights inclusive and a control period of no traffic noise exposure in the third week. For the remaining subject pairs, the noise exposure occurred during the third week with the first week being the control period. The testing of the subjects’ abilities to perform tasks was conducted on Monday, Wednesday and Friday mornings during the first and third weeks of the test period. The second week of the test period was used to allow subjects to return to their normal routine between the two weeks of performance testing. Sleep disturbance and noise levels were monitored continuously over the test period.

Couples were selected on the basis of no snoring or apnoea, normal PSQI, no shift workers, preferably no babies and normal hearing. Couples also had to complete a questionnaire relating to personal attitudes. Houses had to be in a quiet neighbourhood with easy access for equipment and space in the bedroom for the test equipment.

Sleep disturbance was monitored using an actimeter worn on the wrist. The actimeter measures movement events above a threshold movement. The data from the actimeter can be downloaded to a PC for analysis.

Traffic noise was generated using a computer with sound card and loudspeakers. Recordings of vehicle noise were stored as digital .wav files in the computer. A computer program selected these sound files for playing in a programmed sequence to represent traffic on a busy road throughout the night. A sound level meter, controlled by the computer, was used to record one second A-weighted Lₐₐₐ values through the night. These recordings can be compared with those levels expected to be generated by the computer to check system operation and also check for extraneous noises.

Subjects were required to undertake a number of performance tests including the Psychometer Vigilance Task, the Karolinska Sleepiness Scale, the Profile of Mood States, Subjective Effort Questionnaire and the Stanford Sleepiness Scale. The data obtained in this study will enable the influence of night-time traffic noise exposure on task performance to be assessed. Correlations between traffic noise events and sleep disturbance can also be examined.
Engineering Research

Engineering groups within NAL conduct research and development projects and provide a variety of specialised engineering and acoustical services. NAL engineers, as well as research scientists, contribute strongly to Australian and international Standards concerned with hearing aids, audiometric equipment, noise management, hearing loss prevention, and acoustic measurements.

This section presents reports of four very different engineering projects. One project concerns the measurement of interference to hearing aids arising from use of a new mobile telephone system scheduled to be introduced in 2000. Initial measurements indicate that the new phone system (CDMA) should be far less problematic than the existing system (GSM). This fact, coupled with improvements in hearing aids to reduce their susceptibility to interference, suggests that a high proportion of hearing aid wearers will be able to use the new phones without using any special attachments.

Other projects concern hearing aid batteries, digital hearing aids, and the development of equipment for protecting telephone operators from receiving acoustic shocks.
Acoustic shock protection and intelligibility enhancement for telephone operators

(This project was carried out as part of the CRC for Cochlear Implant, Speech and Hearing Research)

Investigators: Michael Fisher, Amar Gorur, Harvey Dillon, Hugh McDermott

1University of Melbourne

Background: Occasionally, intense unwanted signals occur within the telephone network. These signals, termed ‘shrieks’ are typically narrow band in nature and exhibit a piercing sound. Telephone operators who hear these unwanted signals through their headsets can experience great discomfort and temporary or permanent hearing damage. These occurrences are called ‘acoustic shocks’. The problem is heightened in call centres where many operators work together in one room as they need greater sound level from their headsets to overcome background noise.

The acoustic shock problem has been long-standing within Telstra and other telephone networks. Telstra has greatly reduced the number and severity of the incidents by using headset amplifiers that limit the maximum sound level from the headsets. However, this has not provided an adequate solution, as the limited level of the speech from the headsets can make it difficult to understand in noisy call centres. Also, the limiting can decrease the speech quality.

NAL and a product development section of Telstra have been engaged in a collaborative project to develop a headset amplifier that provides both improved intelligibility and greater hearing protection for telephone operators.

Research and Development: NAL has devised, implemented and tested a sophisticated digital signal processing scheme that limits the maximum sound pressure, referred to the eardrum, in a highly controllable way, and with minimum distortion. The scheme uses and extends concepts that we have previously applied to hearing aids. Details of the processing are necessarily confidential because the device has extensive commercial potential.

However, one of the key features of the scheme is its ability to identify shrieks and attenuate them while leaving speech relatively unaffected. The scheme also reduces variations in the loudness of calls to give the telephone operators a more comfortable listening experience with less need to manually adjust the volume.

Findings: Telstra recently conducted a field trial to assess the device in a call centre with a particularly strong history of acoustic shocks. The operators completed pre- and post-trial surveys that were assessed by independent audiological consultants. The results showed a significant improvement in the operator’s perceived understanding of speech when using the device. There was also significantly less adjustment of the volume control required when using the device compared to the existing headset amplifier. No acoustic shocks were perceived by the operators. (It is possible that none occurred).

Following this successful field trial, the product development section of Telstra with which NAL has collaborated has now negotiated sales of the device to their operational section. They are licensing the complete device, including our software, to an Australian manufacturer. NAL also assisted another division within Telstra in setting specifications for devices of this type. In addition, some of the signal processing algorithm developed by NAL for this project has been purchased by Telstra to incorporate into their emergency roadside telephones, demonstrating further applications and income from the original project.

Significance: The project will lead to the protection of hearing of phone operators, to increased ease of communication by them, and to reduction of work-related health costs in the telephone industry. It will also lead to manufacturing activity in Australia, and will generate a small income for the CRC that will help fund future research.
Hearing Aids and CDMA Digital Mobile Phones

**Investigators:** Eric Burwood, W. Crichton

Many hearing aid wearers have been able to successfully use the Analogue Mobile Phone System (AMPS) by holding the mobile next to their hearing aid and relying on acoustic coupling. The AMPS network will shut down in most metropolitan and regional areas at the end of 1999 and in other areas during the year 2000. Currently most hearing aid wearers do not have hearing aids that are compatible with the Global System for Mobile Communications (GSM) digital mobile technology unless using an accessory such as a hands-free kit or inductive neck loop. There was concern amongst many hearing aid wearers that they would not have a mobile telephone service equivalent to the AMPS system.

In Australia, Telstra has introduced a new type of digital mobile phone system during 1999. It uses Code Division Multiple Access (CDMA) technology and will provide reasonably equivalent coverage to the existing AMPS system. During 1999, the National Acoustic Laboratories commenced Phase 1 of a research project: “Assessment of Interference to Hearing Aids used in Australia by CDMA Digital Mobile Phones”, to characterise the interaction between CDMA phones and hearing aids.

The CDMA mobile phone used in this research has a “clam” type construction. This mobile opens similar to a clamshell with the antenna situated near the hinge of the “clam” and positioned more away from the head than is the case with a small “brick” type of construction. The “clam” mobile is quite small when shut and measures about 5 to 6 cm wide, 9.5 cm long and 2.5 cm deep with the retracted antenna extending 3 cm from the hinged end of the case.

Depending on speech activity, CDMA handsets transmit the voice data at different rates known as “vocoder rates”. These rates are characterised as full, half (½), quarter (¼), eighth (⅛) or variable. Typically, CDMA phones transmit at full rate when speech activity is continuous and drop to ⅛ rate during idle periods in the speech. This vocoder rate reduction decreases the handset’s average transmission power, which increases battery life and reduces the interference experienced by each user.

Special test software was used to control the handset power and vocoder rate. For the class of handsets used with the CDMA network, the standard specifies a tolerance, for the open loop control maximum power, of 18-30 dBm with a nominal power of +23dBm (200 mW). For the handset used in this research, the maximum test power that could be achieved was +27 dBm (500 mW). In a CDMA system, interference control is very important to maximising system capacity, so the handset will generally operate on much lower power levels when under network control.

A small sample of hearing aid models fitted to Australian hearing clients was selected that was estimated to cover slightly over half of all hearing aid users in Australia. During the testing program subjective evaluation of any interference was assessed by two people whose hearing was measured to be on the lower limit of the normal range. The criterion for “usability” is based on the level of interference generated in the hearing aid by the CDMA mobile phone, being described as “not perceptible”, or “just perceptible”.

From the Phase 1 research studies carried out at the National Acoustic Laboratories it is possible to estimate that most hearing aid users, who can successfully use a normal telephone or analog mobile phone, will be able to successfully use a CDMA digital mobile phone. These hearing aid users will not need to use accessories, such as hands free kits, or neck loops under most situations encountered in day to day activities.

When present, interference to hearing aids from CDMA technology has a “static-like” sound. There may be some circumstances where some hearing aid users may experience difficulties, such as in fringe reception areas, in a lift, or towards the centre of large concrete-steel buildings.

As a general guide, it is recommended that hearing aid users test the CDMA mobile phone technology with their hearing aid before finalising any purchase agreement. CDMA mobile displays indicate whether the area has strong or weak reception. Typically four or five bars are used to indicate strong reception and one bar is used to indicate weak reception. Hearing aids are more prone to experience interference in weak reception areas. It is
recommended that a client move towards the
centre of the building to seek out a weak
reception area and dial a known phone number
to test the mobile. It may be necessary to move
out of the store to find a weak reception area.
Under these conditions if interference is not
perceived, or is just perceptible, then the hearing
aid will be compatible with the CDMA mobile
phone. If interference is perceived as being
annoying then an accessory may be required to
create some distance between the hearing aid
and mobile phone.

When using any phone if “feedback”, a
whistling sound, occurs then increase the phone
volume to maximum and move the handset a
little further from the hearing aid, or reduce the
hearing aid volume control, to compensate for
the additional sound level. Also angling the
handset slightly upwards may also reduce the
“feedback” whistling sound.

The first phase of this research is now complete.
The second phase will involve objective physical
measurements of hearing aid immunity using
waveguide apparatus and then relate these to
objective assessments of listening tests by
hearing aid wearers. A range of hearing aids,
representative of those in general use, will be
selected for the second phase of this research. It
is expected that the results from the second
phase of this research may form the basis for
any proposed change to the Australian/New
Zealand immunity standard (AS/N ZS 1088.9)
for hearing aids.

High Current Limitation
of Hearing Aid Batteries

Investigator: Eric Burwood

Zinc-air batteries are currently the main
batteries of choice for hearing aid use. They
have approximately double the battery capacity,
or life, when compared to alternative available
battery chemistries. The trend towards
miniaturisation of hearing aids is reflected in
the application of smaller batteries but still
expecting high output power from the hearing
aid. The corollary of this is that for a given size
hearing aid battery more power is expected
from this cell than what would be expected
some years ago. Under demanding operating
conditions the terminal voltage for zinc-air cells
decreases, even for fresh or relatively new cells.
When subjected to light loads, zinc-air cell
terminal voltage is typically between 1.25 and
1.30 volts. Under medium load conditions the
terminal voltage may drop to between 1.2 and
1.25 volts and for heavy loads the terminal
voltage may be between 1.15 and 1.2 volts.
Under severe loading conditions the terminal
voltage may drop below 1.10 volts even though
there is still a significant amount of capacity left
in the cell.

These loading conditions may result in adverse
operation of the hearing aid. In programmable
and digital hearing aids there is typically a reset
voltage level usually set between 0.7 and 1.05
volts. When switched on, the hearing aid checks
that the battery voltage is above the reset level
then enables the operation of the hearing aid to
some predefined settings. Conversely when the
battery terminal voltage drops below the reset
level then the hearing aid is disabled. This reset
action ensures that battery voltage is sufficient
to provide the hearing aid user with good
quality sound. However, battery performance
can vary between manufacturers and even
between cells of the same model. Also zinc-air
battery performance may change with varying
temperature and humidity conditions. Under
some circumstances when some hearing aids are
set to their maximum power settings and used
in high ambient noise conditions it may be
possible for the battery voltage to momentarily
be forced below the reset level and then the
hearing aid will be shut down. The battery
voltage can then recover a little and the
terminal voltage may now be a little above the
reset level so the hearing aid is enabled again to
its predefined settings. This reset action may create
another problem for the hearing aid user if the
volume control had been adjusted to a different
level than what had been predefined. If this
action repeats, the hearing aid user may
interpret it as an intermittent fault and return
the hearing aid to the supplier whom then tests
the hearing aid with a new battery and finds
that it is performing to specifications. This type
of action is usually more prone to occur during
the latter part of the battery life cycle for what
are very high powered hearing aids for the
particular battery size. Therefore it should be
noted that this might apply to lower powered
hearing aids that use very small batteries as well
as higher powered hearing aids using larger
batteries. Also it may be perceived due to variations in ambient sound conditions. Hearing aids of similar performance using analogue circuitry alone may not be perceived by the hearing aid user to suffer the same step changes in performance. Under similar conditions during the latter part of the battery life the analogue hearing aid when subjected to high noise levels may be perceived as having increased distortion. However, when moving to a lower noise environment the hearing aid settings would not be changed and the hearing aid would operate as expected by the hearing aid user. At the very end of battery life, when the battery voltage is below one volt, some analogue designs may behave erratically. Hearing aid designers and those who set hearing aid performance requirements need to keep abreast of the limitations imposed by battery technology on hearing aid performance. In the design cycle it may be more prudent to forego a couple of decibels in maximum output power rather than set the limit at a higher level that can only be achieved with a fresh battery and that may result in a hearing aid user having a potential reliability problem when in high sound levels during the latter half of the battery life.

**Potential Gain Limitation for Digital Hearing Aids**

**Investigator:** Eric Burwood

The maximum gain for a given hearing aid design is governed by a number of parameters such as: case design; microphone mount design; receiver (earphone) mount design; orientation of transducers and layout for the connecting wires to the transducers. Also the materials selected for the plastic and rubber parts has a considerable influence on the maximum usable gain that can be achieved. The maximum full-on-gain must also allow a margin of safety before feedback occurs and to cater for production tolerances encountered in the manufacturing process. Otherwise feedback resonant peaks may occur in the frequency response of the hearing aid at particular frequencies. Various types of feedback can occur in hearing aids such as acoustic feedback and vibration feedback between receiver and microphone transducers as well as magnetic feedback between the receiver and telecoil. The design process must optimise all the above and other parameters to meet the required maximum full-on-gain.

The phase response of the receiver varies with frequency over the bandwidth of the hearing aid. In traditional analogue hearing aids and programmable hearing aids that control analogue circuitry, the polarity of the earphone terminals can also be selected to change the phase of any signal in the feedback path at the most critical frequency to obtain maximum gain without the possibility of feedback.

In digital signal processing hearing aids the microphone signal is amplified using analog circuitry then converted into a digital signal where many parameters can be adjusted and set for the hearing aid user. Some of the typical parameters that may be set are the gain, power level, frequency response, automatic level controls and many more. This digital processing does not happen instantaneously resulting in a small delay between the signal entering and leaving the hearing aid. In traditional analog and programmable hearing aids this delay is not significant as it is only a small fraction of a millisecond. In current digital hearing aids this delay may be of the order of one to tens of milliseconds. Therefore the sound leaving the hearing aid may be delayed in time by the equivalent of up to several wavelengths of the signal entering the hearing aid. At a number of frequencies over the bandwidth of the hearing aid the phase of the signals entering and leaving the hearing aid will alternate between being in phase and out of phase. At some frequency near any gain peaks in the frequency response there is a very high probability that the phase of any feedback signal will reinforce the hearing aid signal and reduce the feedback margin.

Consider a high gain hearing aid design that has been optimised for maximum full-on-gain for analogue or programmable circuitry. If the electronics is replaced by digital hearing aid circuitry, this may result in a number of unwanted resonant artifacts in the frequency response curve at maximum full-on-gain. This effect is due to the reduced feedback margin at the critical frequencies. The full-on-gain performance for the digital hearing aid may need to be reduced by several decibels to allow...
sufficient safety margin for reliable operation and to obtain a good frequency response curve. The critical frequencies are different depending upon the total design including all phase changes and whether the output transducer signal needs to be in phase or 180 degrees out of phase with the signal entering the hearing aid to cause positive feedback problems within the total hearing aid system.

For example, consider a digital hearing aid that has a 2 millisecond delay between the signals entering and leaving the hearing aid. For this simple analysis, internal phase changes have been neglected.

If a zero (0, 360, 720 etc.) degree phase shift is required to produce positive feedback then the critical frequencies are given by:

\[ f = \frac{n}{T} \]

Where: \( f \) is the critical frequency in Hertz where positive feedback may occur; \( T \) is the delay in seconds, between the signals entering and leaving the hearing aid; \( n \) is an integer, e.g. 1, 2, 3, 4, 5.

For this example the critical frequencies are 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000 Hertz...

If a 180 (180, 540, 900 ...) degree phase shift is required to produce positive feedback in the total system, then the critical frequencies are given by:

\[ f = \frac{n}{2T} \]

Where: \( f \) is the critical frequency in Hertz where positive feedback may occur; \( T \) is the delay in seconds, between the signals entering and leaving the hearing aid; \( n \) is an odd integer, 1, 3, 5, 7, 9 ...

For this example the critical frequencies are 250, 750, 1250, 1750, 2250, 2750, 3250, 3750 Hertz...

In both the above cases the frequency spacing is 500 Hertz. If the delay in digital signal processing is decreased to 1 millisecond then the lowest critical frequency is doubled and the spacing between critical frequencies is also doubled to 1000 Hertz. If the delay is increased to 10 milliseconds then the lowest critical frequency is lowered five fold and the spacing between critical frequencies is now only 100 Hertz.

Regaining this lost gain in a digital hearing aid is difficult, especially if the case design and transducer mounts have been optimised. Some digital hearing aids use numerical algorithms to reduce the effects of feedback over the hearing aid bandwidth. This approach may recoup some, or all of this lost gain. Also as processing speeds increase as technology improves, then the delay between signals entering and leaving a digital signal processing hearing aid may decrease which will reduce the number of critical frequencies. If the processing delays can be reduced sufficiently, then the first critical frequency may be placed above the bandwidth of the hearing aid.

In summary, for a given hearing aid mechanical design, digital signal processing electronics may lower maximum full-on-gain below that which can be achieved using traditional analog or programmable analogue circuitry unless the digital processor includes a feedback suppression algorithm. This loss of maximum gain for digital hearing aids has not been fully quantified but is expected to be several decibels, for example, 6 decibels. Note that a loss of maximum gain in digital hearing aids may apply to both microphone and telecoil operation.
NAL scientists enjoy regular and frequent communications with professional colleagues and members of the public. Here is a little background to some of the publications and presentations listed in the appendices and some information about visitors.

Publications

The 23 articles that were published or accepted during the year are listed in Appendix A. These cover a variety of topics in both the hearing aid fitting and hearing loss prevention areas.

A highlight of hearing loss prevention was a publication in the Medical Journal of Australia by Eric LePage and Narelle Murray. This research that showed that the protracted use of personal stereo headsets can result in ear damage comparable to that caused by working in heavy industry. These results are of particular interest because they refute previous research that suggested that there is minimal risk of damage from such recreational noise. The previous negative results may be explained by the use of a less sensitive measurement technique (audiometry rather than otoacoustic emission testing) together with the fact that ear damage, from whatever noise source, accumulates over many years. This research is very significant because it shows that this very common form of recreational noise needs to be controlled to prevent widespread hearing losses in the community. The publication drew considerable local and international media interest.

The first of a group of articles on NAL’s new non-linear hearing aid prescription procedure appeared in the Hearing Journal. This provided an overview of the rationale and nature of the procedure and an indication of how it differs from other procedures, both with respect to rationale and the prescriptions provided. The procedure has generated considerable interest, resulting in significant sales of the associated software. Several other articles are being prepared for scientific or industry journals. These will provide details of the procedure’s derivation and rationale, will compare prescriptions with those of other procedures, will show how the software can be used to fit a variety of advanced hearing aids, and will discuss the relationship of audibility to speech intelligibility.

Another highlight was the publication of two articles by Harvey Dillon and Lydia Storey. These provided the theoretical derivation and research evidence for a new procedure for prescribing the saturation sound pressure level of hearing aids. Further articles, by Harvey Dillon, Chris Barker and others, reported client preferences for compression thresholds. A pair of articles by Denis Byrne, Teresa Ching, Jeanette Jordt and others discussed issues in selecting amplification for hearing-impaired children.

The Hearing Journal’s review of the best articles published in 1998 selected four NAL publications. One article by Denis Byrne was mentioned in both the Rehabilitation and Hearing Aid sections. This was published early in 1998. (Byrne D. Hearing aid clinical trials: Specific benefits need specific measures, Am J Audiol, 7, 17-19.) The article questioned a recommendation for using a standard battery of tests to assess the benefits of new types of hearing aids. It was argued that, as benefits are many and varied, the evaluation procedures used in any clinical trial should be chosen to
Narelle Murray addresses a group of paediatricians about hearing loss prevention.

John Macrae cuts the cake at his farewell. He is supervised by Australian Hearing’s Managing Director, Peter O’Byrne, and watched by hungry colleagues.

The most thought provoking point was the finding that the use of loudness discomfort measurements, in addition to hearing threshold measurements, did not make any improvement in predicting the required saturation sound pressure level.

Conferences and Presentations

Scientists participate in conferences, seminars and workshops to learn from other scientists, through presentations and informal discussions, and to disseminate their own research findings and ideas. To serve these ends, NAL scientists participate regularly in a variety of national and international events. They also disseminate research and contribute to education by presenting talks at public meetings and through the media.

Invitations to speak at major conferences are a very significant mark of recognition of a scientist’s work. During the year, NAL scientists accepted such invitations to be keynote, guest or featured speakers at conferences in China, Singapore, USA, Argentina, New Zealand and Belgium.

6th Asia-Pacific Conference on Deafness
Beijing, China, 3 – 6 August 1998

Denis Byrne was an invited speaker for this conference which is held every second year. It is a large multi-disciplinary meeting of professionals (audiologists, otolaryngologists, teachers-of-the-deaf) who are predominantly, but not exclusively, from the Asia-Pacific region. In a plenary session, Denis talked on the significance of sound localization for hearing aid fitting. He gave another talk on fitting non-linear hearing aids, as part of a symposium on hearing aid fitting. This covered general principles and outlined the NAL non-linear fitting procedure. The conference hosts provided simultaneous translations of the featured talks.

Jackson Hole Rendezvous
Jackson Hole, Wyoming, 12 – 16 August, 1998

Harvey Dillon was the keynote speaker at this biennial conference which aims to present the most up-to-date information on a selected topic within audiology. The theme of this conference was new amplification concepts for the new millennium. Harvey gave one paper on how to select parameters for the various types of compression used in hearing aids, including the NAL-SSPL procedure for prescribing maximum output and the NAL-NL1 procedure for prescribing non-linear hearing aids. This brought together the findings of several NAL...
experimental and theoretical investigations. He gave a second paper on using the COSI and the HAUQ to measure the outcomes of rehabilitation.

**XXIV International Congress of Audiology**
Buenos Aires, Argentina, 30 August – 2 September 1998

Denis Byrne was an invited speaker who presented one of three talks that formed a special session on hearing aid fitting. His talk made a plea for taking a broader view of hearing aid fitting and presented a conceptual model of a range of hearing aid fitting objectives and strategies. The discussion that followed this presentation prompted the idea of undertaking a collaborative project with other members of the International Collegium of Rehabilitative Audiology (see report on SHAPE project).

**A Sound Foundation Through Early Amplification**
Chicago, 29 – 31 October, 1998

Harvey Dillon was an invited speaker at this conference on paediatric rehabilitation. His talk was on what amplification characteristics are optimal for children. This was a controversial talk on a controversial topic, as many of the other talkers asserted, largely without any direct evidence, that amplification characteristics for children are different than for adults. The conference covered all aspects of paediatric rehabilitation, including the expectations of parents regarding service delivery. Proceedings will be published in 2000.

**International Symposium on Comprehensive Management of the Hearing-impaired Child**
Singapore, 26 – 28 March 1999

Teresa Ching was the keynote speaker at this international symposium for parents, teachers, audiologists and ENT surgeons. She presented a talk that explained why amplification that makes more speech audible is not always better for understanding speech. An audiological workshop was then conducted in which the NAL non-linear prescription was presented and compared with an alternative procedure. Teresa also gave two talks emphasizing the importance of individual hearing aid evaluation. Two procedures developed at NAL for evaluating children were introduced together with a display that enables teachers and parents to visualize how much speech is audible to a child when hearing aids are worn.

**Annual Conference of the New Zealand Audiological Society**
Auckland, New Zealand, 20 – 23 May 1999

Denis Byrne was one of the three keynote speakers for this conference. He presented one talk in which he outlined the derivation and principles of the NAL non-linear prescription procedure and showed how its prescriptions compared with those of other procedures. In a second talk, Denis presented the SHAPE model of fitting objectives and strategies and offered a philosophical discussion of the future of audiologists in fitting hearing aids. The latter centred around the dilemma that, on one hand, new hearing aid designs offer vastly greater capabilities but, on the other hand, it has become increasingly difficult to understand what is happening in the fitting process. It was argued that, despite the difficulty of understanding increasingly complex forms of amplification, audiologists must do this in order to continue fitting hearing aids in a professional, scientific manner rather than being driven by marketing hype.
Library

The separation from the Dept. of Health Healthnet library system was complete from 1 July 1998 and the library has now completed its first full year of operation as an independent Special Library. Apart from needing to establish an independent automated library catalogue this has not proved to be a major change for the library operations. Access to the library catalogue is available on the research network and is planned to be available to all staff on the Australian Hearing network and to the public on the Australian Hearing web-site in the near future. The closing of all Dept. of Health branch libraries has resulted in an increase in the number of requests received from Hearing Centres around Australia.

The depth of the library collection in the fields of audiology and hearing aids continues to attract a large volume of inter-library loans from academic institutions throughout Australia. The library collection is listed in the National Bibliographic Database maintained by the National Library of Australia and continues to be a net lender on the Inter-library loan network. The library is also a member of Gratisnet, a national co-operative network of Medical Libraries.

Students in Audiology at Macquarie University continue to use the library in large numbers for access to material not held elsewhere in Australia. While public access to the library is not possible access is available by appointment to post-graduate students in audiology, professional colleagues and research workers. Members of the public have access to the library collection through the inter-library loan system via their public library.

The National Acoustic Laboratories research publications for 1997 and 1998 have been compiled to form a bound volume. This updates the two sets previously produced that included all "Hearing and Hearing Aids" publications (volumes 1-8) and all "Noise Effects and Hearing Loss Prevention" publications from 1942 to 1996. The new volumes covers publications in both areas and is designated "Vol. 9, Hearing, Hearing Loss Prevention, Hearing Aids". Copies of the volumes have been presented to the National Library and to the universities that conduct courses in audiology or acoustics. Copies are also held in the Australian Hearing library and by senior research and some other staff.

EHIMA World of Hearing
Brussels, 27 – 29 May, 1999

Harvey Dillon was an invited speaker at this new conference organised by the European Hearing Instrument Manufacturers’ Association. The theme of the conference was to showcase the contributions that modern hearing aids can make to people with hearing impairment. Harvey’s talk was on the performance benefits offered by advanced processing features in currently available hearing aids, and on what type of people can benefit from these features. The conference exhibition was advertised widely and was open to the general public.

Visitors

Research staff enjoyed professional discussions with a number of visitors to the National Acoustic Laboratories. Visitors are listed in Appendix C.
Appendices

Appendix A - List of Publications


Appendix B - Presentations and Talks

Conference Presentations


Byrne, D. and Noble, W. Significance of sound localization for hearing aid fitting. 6th Asia-Pacific Conference on Deafness, Beijing, 3-6 August 1998.


Dillon, H. The Use of COSI and the Hearing Aid Users Questionnaire to monitor outcomes. Keynote address to the Jackson Hole Rendezvous, Wyoming, August 1998.

Dillon, H. Fitting a wide dynamic range of speech into a narrow dynamic range of hearing. A Sound Foundation Through Early Amplification, Chicago, October 1998.

Dillon, H. The NAL-NL1 non-linear selection procedure, AAA Convention, Miami, April 1999.


Other Public Talks


LePage, E.L. Understanding hearing loss: Why it is so difficult to get young people to respect their ears. SHHH Australia; Turramurra. 20 March, 1999.

LePage, E.L. And the Band Played on... How our ears fail gracefully. Better Hearing Australia, Concord, 30 April, 1999.
Murray, N.M. Hearing Awareness Week – 4 presentations to various interest groups in Hobart, 25-26 August, 1998.


Williams, W. Hearing Awareness Week, 2 presentations to interest groups, August 1998.
1. Opening address on the topic of noise prevention, 24 Aug 1998

**Appendix C – Visitors**

<table>
<thead>
<tr>
<th>Mr Peter DeGraaff</th>
<th>National Manager, Office of Hearing Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr Leong Mar</td>
<td>AMBRI</td>
</tr>
<tr>
<td>Mr Owen Hill</td>
<td>Director, National Nanofabrication Facility</td>
</tr>
<tr>
<td>Dr Errol Harvey</td>
<td>Deputy Director, Industrial Research Institute, Swinburne</td>
</tr>
<tr>
<td>Mr Peter Finnerup</td>
<td>General Manager, Bernaforn, Switzerland</td>
</tr>
<tr>
<td>Mr Yiap Kum Hang</td>
<td>Consultant Audiologist, Singapore</td>
</tr>
<tr>
<td>Dr Sun Xi Bin</td>
<td>Deputy Director, China Rehabilitation Research Centre for Deaf Children, China</td>
</tr>
<tr>
<td>Mr Tinggui Xu</td>
<td>Director, Jiangsu Hearing Rehabilitation Centre, China</td>
</tr>
<tr>
<td>Mr David Malcolm</td>
<td>Managing Director, Starkey Laboratories, Sydney</td>
</tr>
<tr>
<td>Mr Kiyoshi Ishiyama</td>
<td>Managing Director, Starkey, Japan</td>
</tr>
<tr>
<td>Mr Touben Poulsen</td>
<td>Technical University of Denmark, Denmark</td>
</tr>
<tr>
<td>Mr Barak Dar</td>
<td>Managing Director, AVR Communications, Israel</td>
</tr>
<tr>
<td>Prof. Adrian Davis</td>
<td>Medical Research Council, Institute of Hearing Research, UK</td>
</tr>
<tr>
<td>Prof. Guido Smoorenburg</td>
<td>Head, Hearing Research Laboratories, the Netherlands</td>
</tr>
<tr>
<td>Dr Bo Engdahl</td>
<td>National Institute of Public Health, Oslo, Norway</td>
</tr>
<tr>
<td>Mr Anthony Brammer</td>
<td>National Research Council, Canada</td>
</tr>
<tr>
<td>Dr Laurie Heller</td>
<td>Research Scientist, Naval Submarine Medical Research Laboratory, USA</td>
</tr>
<tr>
<td>Dr Richard Price</td>
<td>Senior Research Scientist, US Army Research Laboratory, USA</td>
</tr>
<tr>
<td>Dr Åke Olofsson</td>
<td>Karolinska Institute, Stockholm</td>
</tr>
<tr>
<td>Ms Mary Murnane</td>
<td>Deputy Secretary, Dept. of Health and Aged Care</td>
</tr>
<tr>
<td>Dr Kalyani Mandke</td>
<td>Pune Advanced Auditory Research, Pune</td>
</tr>
<tr>
<td>Dr Dong-yi Han</td>
<td>Chairman and Professor, Dept of Otorhinolaryngology, Chinese PLA General Hospital, China</td>
</tr>
<tr>
<td>Mr Raimund Martin</td>
<td>Siemens, Germany</td>
</tr>
<tr>
<td>Ms Janette Oliver</td>
<td>Cochlear Ltd., Australia</td>
</tr>
<tr>
<td>Ms Boel Heister Trygg</td>
<td>Lund University, Sweden</td>
</tr>
<tr>
<td>Ms Ingrid Lennart</td>
<td>Lund University, Sweden</td>
</tr>
<tr>
<td>Ms Ewa Holst</td>
<td>Lund University, Sweden</td>
</tr>
<tr>
<td>Ms Kajsa Johansson</td>
<td>Lund University, Sweden</td>
</tr>
<tr>
<td>Mr Oki Han</td>
<td>Dong San Hearing &amp; Speech Centre, Seoul, Korea</td>
</tr>
<tr>
<td>Prof. Brian Moore</td>
<td>Psychology Dept., University of Cambridge, UK</td>
</tr>
<tr>
<td>Dr Gus Mueller</td>
<td>Castle Pines, USA</td>
</tr>
<tr>
<td>Dr Ole Drylund</td>
<td>GN Danavox, Denmark</td>
</tr>
<tr>
<td>Dr Bob Oliveira</td>
<td>Hearing Components, USA</td>
</tr>
</tbody>
</table>
## Appendix D

### NAL Publications/Materials – Order Form

Please send me the items as marked below:

<table>
<thead>
<tr>
<th>NO.</th>
<th>Description</th>
<th>Unit price</th>
<th>Qty</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC5830</td>
<td>HASP (Hearing Aid Selection Procedure) Software (includes Manual)</td>
<td>280.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4376</td>
<td>NAL-NL1 Selection Procedure (Software and Manual)</td>
<td>189.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>or US$139.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1266</td>
<td>Non-linear Hearing Aids and the NAL-NL1 Prescription Procedure (set of 2 VHS videos with notes)</td>
<td>69.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4380</td>
<td>Speech Recognition Materials (AB Wordlists and NUCHIPS) on CD</td>
<td>58.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4381</td>
<td>COMMTRAM</td>
<td>55.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4382</td>
<td>COMMTRAC</td>
<td>55.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4384</td>
<td>Hearing Aid Selection Slide Rules (NAL-RP procedure)</td>
<td>30.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4385</td>
<td>PLOTT Test by Geoff Plant</td>
<td>55.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4386</td>
<td>THE PLOTT SCREENING TEST and THE PLOTT SENTENCE TEST</td>
<td>70.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4387</td>
<td>Percentage Loss of Hearing Tables (1982)</td>
<td>25.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4388</td>
<td>Improved Procedure for Determining % Loss of Hearing</td>
<td>25.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NAL Report 118 (1988)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4389</td>
<td>A Procedure for Determining Percentage Loss of Hearing of Clients with Abnormally Poor Speech Discrimination (NAL Report 124)</td>
<td>25.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4390</td>
<td>Criteria for Assessing Hearing Conservation Audiograms (NAL Report 80)</td>
<td>25.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4391</td>
<td>SYNTREX – Synthetic Training Exercises for hearing impaired adults – Therapist and Client Handbook</td>
<td>70.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4392</td>
<td>TACTAID II Training Program</td>
<td>55.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4393</td>
<td>Hearing Loss Simulation – Filtered Speech and Tinnitus Cassette</td>
<td>25.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4396</td>
<td>A Home Programme for Preschool Vibrotactile Aid Users</td>
<td>40.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Name

Company/Organisation

Address

City State Postcode

Country Telephone Fax

I enclose my cheque/money order for $__________ payable to Australian Hearing

OR Please charge my

☐ MASTERCARD ☐ BANKCARD ☐ VISA ☐ AMERICAN EXPRESS Expiry Date __________

Signature ______________________________

Mail to: Research Executive Officer, National Acoustic Laboratories, 126 Greville Street, Chatswood 2067 Australia

Or Fax to: +61 2 9411 8273 (Attn: Research Exec. Officer) FOR PAYMENT BY CREDIT CARD ONLY

For further information contact: Telephone: +61 2 9412 6862 Facsimile: +61 2 9411 8273 Email: Research@nal.gov.au