

How does auditory training work? Joined up thinking and listening

Melanie Ferguson, PhD^{1,2}, Helen Henshaw, PhD¹

¹NIHR Nottingham Hearing Biomedical Research Unit, Otology and Hearing Group, Division of Clinical Neuroscience, School of Medicine, University of Nottingham, Nottingham, UK

²Nottingham University Hospitals NHS Trust, Nottingham, UK

Corresponding author:

Dr Melanie Ferguson

NIHR Nottingham Hearing Biomedical Research Unit

Ropewalk House

113 The Ropewalk

Nottingham, UK

NG1 5DU.

Tel: (+44)115 8232619

Fax: (+44)115 8232615

Email: melanie.ferguson@nottingham.ac.uk

Conflicts of interest and source of funding: This paper presents independent research funded by the National Institute for Health Research (NIHR) Biomedical Research Unit Programme. The views expressed are those of the authors and not necessarily those of the NHS, the NIHR or the Department of Health. There are no conflicts of interest.

Abbreviations:

ICF International Classification of Function

LACE Listening and Communication Enhancement

MRI Magnetic resonance imaging

RCT Randomized controlled trial

PICOS Participant, interventions, comparison, outcomes, study design

SNR Signal to noise ratio

WHO World Health Organization

Abstract

Auditory training aims to compensate for degradation in the auditory signal, and is offered as an intervention to help alleviate the most common complaint in people with hearing loss, understanding speech in a background noise. Yet there remain many unanswered questions. This review article describes some of the key pieces of evidence that assess the evidence for whether, and how, auditory training offers benefit to adults with hearing loss. The evidence is clear that improvements occur on the trained task, however transfer of that learning to generalised real-world benefit is much less robust.

For more than a decade, there has been an increasing awareness of the role that cognition plays in listening. But more recently in the auditory training literature, there has been an increased focus on assessing how cognitive performance relevant for listening may improve with training. We argue that this is specifically the case for measures that index executive processes, such as monitoring, attention switching and updating of working memory, all of which are required for successful listening and communication in challenging or adverse listening conditions.

We propose combined auditory-cognitive training approaches, where training interventions develop cognition embedded within auditory tasks, are most likely to offer generalized benefits to the real-world listening abilities of people with hearing loss.

Keywords: Auditory training, Hearing loss, Working memory, Attention, Communication, Hearing aids, Executive function, Speech perception.

Learning Outcomes:

1. The learner will be able to describe four ways to assess the evidence for whether or not auditory training is effective for people with hearing loss.
2. The learner will be able to explain how improvements on untrained speech and communication outcome measures may be attributed to executive processes (cognition).

CEU questions

1. Which type of investigation provides the highest level of evidence?
 - a) Case-control studies
 - b) Randomized controlled trials
 - c) Case studies
 - d) Expert opinion
 - e) Systematic reviews and meta-analyses (correct)

2. Which of the following describes the learning that is *least* likely to be representative of patient benefit from auditory training?
 - a) Generalisation of learning
 - b) Near transfer of learning
 - c) Far transfer of learning
 - d) On-task learning (correct)
 - e) Off-task learning

3. In the phoneme discrimination study (Ferguson et al, 2014), performance on which outcome measure improved pre- to post-training?
 - a) Test of everyday attention: divided attention (correct)
 - b) Test of every day attention: single attention
 - c) Digit span
 - d) Sentences in 8-Hz modulated noise
 - e) Digit triplets in speech-shaped noise

4. Which of the following training stimuli have been shown to result in reduced hearing disability, as measured by the Glasgow Hearing Aid Benefit Profile?
 - a) Listening and Communication Enhancement (LACE)
 - b) Brain fitness
 - c) Luminosity
 - d) Phoneme discrimination training (correct)
 - e) Cogmed RM

5. Which of the following is not considered to be an executive process?
 - a) Attention switching
 - b) Memory updating
 - c) Forwards digit span (correct)
 - d) Divided attention
 - e) Monitoring multiple talkers

Hearing loss results in significant difficulties in communication, which in turn can lead to social withdrawal and isolation, depression, and reduced quality of life.¹ More recently, there is evidence that hearing loss is associated with an increased risk of developing dementia,² and MRI scans show that people with hearing loss have accelerated brain atrophy.³ Over the last decade it has become increasingly evident that listening and communication require the contribution of both sensory and nonsensory factors, such as cognition, motivation and context.⁴⁻⁶ This is particularly the case when listening to speech in adverse conditions, such as in fluctuating background noise or competing speakers.^{7,8} and more so in older listeners.⁹

In order to effectively communicate, whether a hearing loss is present or not, a person needs to access the acoustic information (hearing, a passive process), employ attention and intention (listening, an active process), correctly interpret the acoustic and linguistic information (comprehension, a unidirectional process) and use and transmit this information effectively (communication, a bidirectional process).¹⁰ This concept of communication, based on the WHO International Classification of Functioning, Disability and Health Framework (ICF),¹¹ has been developed further to suggest both positive and negative feedback loops exist whereby not only does improved listening result in better comprehension and communication but the converse also occurs.¹² Consequently, there is an interplay between ‘bottom-up’ and ‘top-down’ processing that is important for successful communication. This interplay has been demonstrated empirically through physiological and neurological studies,¹³⁻¹⁵ studies of the role of cognition in hearing aid users,^{16,17} and in those using advanced hearing aid processing strategies, such as fast acting compression¹⁸ and noise reduction algorithms.¹⁹

Interventions for hearing loss

The main clinical intervention to benefit adults with hearing loss is the use of hearing aids, which have been shown to provide significant benefits in terms of reduction in activity limitations (e.g. difficulties listening to speech in background noise) and participation restrictions (e.g. reduced active participation in social events).²⁰ Despite recent advances in digital technology and improved users' satisfaction with hearing aids,²¹ users often continue to encounter difficulties in noisy and challenging listening environments.^{22,23} Furthermore, a large proportion of people who would benefit from hearing aids do not have them,²⁴ and in those that do wear hearing aids, there are often delays in help-seeking with many people having hearing difficulties for at least 10 years before obtaining hearing aids.¹

When it comes to improving communication for people with hearing loss, it is clear that hearing aids alone are not the only option. A holistic approach to aural rehabilitation has been suggested,²⁵ which includes management strategies to improve sensory deficits such as hearing aids and FM or wireless systems, instruction on technology and communication strategies, counselling to enhance participation in everyday life, and perceptual training. This review article focuses on recent developments in the field of auditory perceptual training. The article highlights work from our own lab, which is grounded in this literature, and is aimed at improving speech perception, cognition and self-reported communication abilities in adults with hearing loss, and identifying how improvements in these domains might best be measured.

Auditory training and the unanswered questions

Auditory training as a means to compensate for the degraded auditory signal in people with hearing loss has been around since the mid-1950s, and until the mid-1990s was primarily delivered verbally, on a one-to-one basis.^{26,27} However, the advent of computer-based

auditory training, either via PC or the internet, provides more widespread, cost-effective and easier-to-deliver training solutions. The added advantage of this approach is that training can be tailored to the individual's performance and conveniently delivered at home. Over the last decade there have been a number of review articles on auditory training that have offered a range of different perspectives, including historical advances,^{27,28} rules and applications of training in adults and children,^{29,30} training-related changes in the brain,^{31,32} and conceptualisation of the potential for auditory training.⁴ Commercial training applications for users of hearing aid and cochlear implants are listed in a number of articles.^{28,33,34}

A number of reviews and research articles have raised a number of pertinent research questions (for a summary, see Table 1), but the question that has been most widely debated has been "Is auditory training effective?". This question has been directly examined by two systematic reviews. Sweetow and Palmer³⁵ reviewed the literature and identified six published articles up until 1996. We followed this up with our own systematic review that identified 13 articles between 1996 to 2012, which used computer-based auditory training in adults with hearing loss.³⁶ Systematic reviews differ from general literature reviews in that they ask a specific research question often using PICOS (participant, intervention, comparison, outcomes, study design) as a guide, use specific eligibility criteria and a systematic research strategy, assess the validity of the findings, and aim to provide robust evidence to support evidence-based practice. Within the hierarchy of evidence, systematic reviews, particularly if supported by a meta-analysis, provide the highest level of evidence.³⁷

Does auditory training work?

We assessed the evidence for this in a systematic review³⁶ by asking a number of questions.

1. Does evidence exist to support improvements on the trained task ('on-task' learning)?

The evidence was clear that for adults with mild-moderate hearing loss, whether hearing aid users or not, on-task learning always occurred for a range of stimuli including phonemes, words and sentences.³⁶ The same trend was shown for cochlear implants users³⁶ with the exception of one study with only 10 in the sample.³⁸ That on-task learning occurs is interesting academically and supports animal models of neuroplasticity.³⁹ However, from a clinical perspective when considering auditory training as an intervention, the following question is more relevant.

2. Does the evidence exist to support improvements in untrained measures to provide patient benefit?

This is often referred to as ‘off-task’, generalized or transfer of learning. Further examination of transfer to untrained measures can be considered on a spectrum of near-transfer (e.g. outcome is close to the trained task) to far-transfer (e.g. outcome is in a different modality or measures a different construct). Traditionally, many training studies of adults with hearing loss have focussed primarily on improving the sensory detection of auditory stimuli (e.g. identification or discrimination) to improve overall speech perception performance. The outcome measures used are often similar speech perception tasks (i.e. near transfer). However, if the aim of auditory training is to improve communication in everyday life, as seen in the models of Kiessling and Sweetow, other outcome measures that are different to the trained task and reflect real-world benefit also need to be considered. For people with hearing loss, these include both self-reported measures of communication and cognition (i.e. far transfer), both of which are important for listening.

In our systematic review,³⁶ the generalization of learning to untrained measures was mixed. It was notable that all the studies used at least one outcome measure of speech perception, yet only two studies used a self-reported measure of communication to tap into perceived real-world benefits,^{12,40} and just one study measured cognition.¹² Although generalized improvements were shown where measured for speech perception (11/13 articles), self-report of communication (1/2) and cognition (1/1), these improvements were inconsistent across studies, and the magnitude of improvement was small and not robust. Similar results have also been shown for speech perception in a review of mainly non-computerised training articles from 1970 to 2009, with a small effect size (Cohen's $d = .35$).⁴¹ Our systematic review highlighted that the quality of the evidence for included studies was very low to moderate. Reasons for this included failure to include a control group and a lack of randomisation, power calculation, and participant and tester blinding. The study that was rated most positively for quality of evidence (moderate) was that by Sweetow and Henderson-Sabes.¹²

Since our systematic review there have been several auditory training studies published that have addressed some of these methodological and quality issues in adults with hearing loss.⁴²⁻

⁴⁴ For example, these studies all included a control group. Moreover, they used outcome measures that assess cognition (i.e. memory and attention), self-reported communication, or both. These studies will be discussed further in a later section.

3. Does any improvement in trained and untrained measures remain after training has ceased (retention of learning)?

To assess the long-term benefits of training interventions for people with hearing loss, follow-up assessment is required. As with many intervention studies, follow-up is often not

conducted.⁴⁵ In our systematic review, retention of learning was assessed in 8/13 articles, and ranged from 4 days to 7 months. All studies showed retention of learning to trained and untrained measures to various degrees with only some reporting the statistical effects. Recently, other studies have demonstrated significant retention of learning,^{43,46,47} with the possibility of ‘top-up’ sessions remaining as a means to maintain learning-related benefits.⁴⁸

4. What is the adherence of individuals with computer-based training?

For an intervention to be considered successful, it is crucial that individuals adhere to the intervention as this is strongly related to outcomes.⁴⁹ This was highlighted in a sub-sample of 50 hearing aid users from large multi-center RCT of LACE that showed those who adhered to LACE training had significantly better outcomes for untrained speech tests than those who were classified as non-adherers.⁵⁰ However, our systematic review showed that adherence, like retention, was reported infrequently (only in 6/13) and defined in different ways (e.g. proportion who completed the training or proportion who dropped out). Where adherence was reported it was high, both for laboratory-based (81%) and home-based interventions (73-100%). This suggests that those who undertake home-based training, where lack of supervision might be expected to result in lower adherence, were at least as compliant as those who undertook supervised training within a laboratory setting. However, this contrasts with a large-scale study that used LACE routinely in clinical practice, where adherence was low with only 30% completing 10 or more of the 20 sessions.⁵¹

Although there have been suggestions as to which factors are important in encouraging high adherence,⁵¹ such as clinician-patient interactions and patient motivations, to date, there has been little research on this. We explored patient motivations for uptake, participation and compliance with a home-delivered phoneme discrimination training programme,⁴³ based on

the Self-determination Theory.⁵² Initial participation in the study was associated with extrinsic motivation (e.g. hearing difficulties), whereas engagement and adherence with training was influenced by intrinsic (e.g. a desire to achieve higher scores), in addition to extrinsic (e.g. to help others with hearing loss) motivations. To gain a better understanding of users' motivations will help inform future theory-driven developments of auditory training, including the consideration of game-play.⁵³

The importance of clinically significant patient benefits

When considering the benefits of interventions for clinical populations it is important to understand what is meant by 'patient benefit'. There are two points of note here, (i) clinical significance, and (ii) individual differences. Research studies in auditory training often report the results of improvement in terms of statistical significance. However a study that shows a statistically significant improvement, particularly in large sample sizes, does not necessarily represent clinically significant patient benefit if the improvement is too small to impact on a patient's everyday life.⁵⁴ As such, the effect size (i.e. the magnitude of improvement) is of critical importance, and has been suggested to be as important, if not more important than statistical significance.⁵⁵ Typically, effect size is described by Cohen's *d* as small, moderate or large (0.2, 0.5, and 0.8 respectively).⁵⁶ Similarly, studies often present research findings in terms of group means, whereas in clinical practice, clinicians are faced with an individual rather than an 'average patient', and so individual differences are important to establish who benefits from training, and how.⁵⁷

Recent advances in auditory training research on communication, cognitive and speech perception abilities: the role of executive processes

When considering outcome measures to show the benefits of auditory training and other interventions, it is important that outcome measures explicitly relate to the needs and goals of the individuals for whom the intervention is aimed at.⁵⁸ Speech perception measures, particularly in noise, have been measured universally in auditory training studies of adults with hearing loss. While it is important to demonstrate measureable improvements in speech perception performance, it is also important for those undertaking training obtain self-perceived benefits in their everyday communication, which is best measured using self-report questionnaires.

Subjective assessment of communication

Our RCT of phoneme discrimination training in 44 adults with mild hearing loss,⁴³ communication, assessed by the Glasgow Hearing Aid Benefit Profile, showed a significant pre- to post-training improvement in the overall score for hearing disability, with a moderate effect size ($d = .51$). There was no significant effect in the waitlist control (no training) group. Although this suggested that training conferred everyday real-world benefits, what was more interesting were the results from the four individual pre-defined situations. The only situation that showed a significant pre- to post training improvement was that for the most complex and challenging listening situation ‘having a conversation with several people in a group’ ($d = .68$). To be able to carry out a conversation in a group, the listener is required to identify the specific speech source against a background of other talkers, and simultaneously monitor and switch attention to other auditory streams or sound sources (i.e. other talkers).^{8,59} This requires the engagement of executive processes that regulate, control and manage other cognitive resources, such as attention and working memory, to aid inhibition, updating and task switching.⁶⁰ There were no significant improvements for the simpler, less challenging listening situations such as ‘having a conversation with one other person when there is no

background noise'. If the benefits of auditory training for everyday communication are primarily evident and relevant to challenging listening situations, then in order to demonstrate these benefits it is important to use outcome measures that are appropriately complex and challenging to be sensitive to the effects of auditory training.

These results were supported by qualitative thematic analysis of open-ended questions from all the participants, in addition to two representative focus groups (n=10 participants).⁶¹ From the open-ended question that asked "what was the best aspect of your experience with the training program?", around one-quarter of the participants provided unprompted reports of improved listening, concentration and attention after they had completed the training. Furthermore, one of the key themes from the focus groups was '*increased concentration, attention and focus in everyday listening*'. Two sub-themes were '*improved listening skills*' and '*development of strategies for listening*', and all but one focus group participant reported that training made them concentrate more. Typical comments were:

"...It [the training] made me concentrate more, it certainly did."

"I think it just made me aware that if I do want to hear what's going off, I've got to pay attention and focus more than I used to."

Taken together, the results from this training study suggest that the benefits of phoneme discrimination training yielded a perception of benefit but this was only demonstrated for situations that index executive processes. To ensure that the benefits of training are captured, future training studies should carefully consider the inclusion of appropriate and sensitive outcome measures at the outset.

Behavioural assessment of cognition and speech perception

The auditory training literature suggests that people improve on what they train on, and this is true also for the cognitive training literature.⁶² Although the LACE programme is referred to as an ‘auditory’ training programme, it also includes cognitive components for auditory working memory, speed of processing task, and auditory closure tasks. Two published LACE studies, one with older adults with hearing loss¹² and the other with younger (19-35 years) normally-hearing people⁶³ showed statistically significant on-task learning for the auditory memory and closure tasks. Furthermore, in one study,¹² generalisation to improvements in untrained cognitive measures was also shown for a Listening Span test (near transfer working memory) and the Stroop Colour test (far transfer speed of processing). Both these tests index executive processes.

Similar results were shown in two studies that used the Brain Fitness program (Posit Science),^{42,64} an auditory-based cognitive training program, with significant improvements in auditory short-term memory and sentence in noise (QuickSIN) shown for the trained but not the control groups. Additionally, there were significant improvements in auditory and visual sustained attention,⁶⁴ and speed of processing.⁴² These results suggest that training can also improve the neurophysiological processes underlying speech perception in noise, specifically improvements in temporal and spectral deficits.

In our own lab, we have carried out a series of auditory and cognitive training studies that used outcome measures of cognition, communication and speech perception.^{43,65,66} These findings have been summarised elsewhere.⁶⁷ For the phoneme discrimination training RCT⁴³ there were no pre-post training improvements for simple measures of cognition (i.e. single sustained attention and simple-digit span working memory) for either the trained or control group. These results are consistent with a large study of multitask cognitive training in 11000

participants, which showed on-task learning but no generalisation to a simple-digit span working memory test.⁶⁸ However, of note in our RCT⁴³ was that generalized far-transfer improvements were shown, with moderate effect sizes, for complex measures of cognition that indexed executive processes. Specifically, these were a test of divided attention (Test of Everyday Attention, TEA) and updating of working memory using a visual letter monitoring task. Notably, there were no improvements in the two speech tests, both of which used energetic noise maskers (i.e. digit triplets in speech-shaped noise, ASL sentence in 8-Hz modulated noise).

This led us to reconsider our speech perception results and ask the question, would a speech test that engaged executive processes, such as an informational masked speech task,⁶⁹ result in improvements in speech perception performance? We examined this further in a phoneme discrimination in noise training study in existing hearing aid users.⁶⁵ Significant pre-post training improvements were shown for a competing speech test that used a male and a female talker (Modified Coordinate Response Measure), with a moderate effect size ($d=.47$), and no improvements for the control period. This contrasts with the results from the speech in (energetic) noise tests and suggests that it may be important to use speech measures that are relevant to the cognitive benefits provided by auditory training. Furthermore, a dual task of listening (AB words in noise) and memory (digit span),⁷⁰ showed highly significant pre-post training improvements with a large effect size ($p < .001$, $d = .77$), but only for an intermediate condition (0 dB SNR) that was neither too easy (quiet) nor too difficult (-4 dB SNR) (see Fig. 1). These results were consistent with our results for cognition and communication from our previous study⁴³ whereby outcome measures need to be appropriately challenging to be sensitive to post-training benefits. Taken together, these results suggest that the value of

auditory training to mediate top-down cognitive skills may be more important than the refinement of bottom-up sensory skills.

Finally, one of the prerequisites for an outcome measure that is used across multiple visits is that it has high test-reliability to minimise measurement error. Across our two auditory training studies test-retest reliability for cognitive and speech perception tests was generally high, and 15/18 measures exceeded an interclass correlation coefficient (ICC) of 0.7 (Table 2). However, it is noteworthy that as test complexity increases, test-retest reliability decreases. For memory, the Digit span is a simple memory storage task whereas the visual monitoring tasks involve working memory that involve executive processing (memory updating) and which have lower ICC than the digit span. For attention, the simpler single TEA task has a higher ICC than the more complex TEA dual task that has a lower ICC, which is further reflected in the differential between the two (dual task decrement). Similarly, this same trend is seen for the speech perception tests that increase in complexity from a digit triplet (word) and sentence in energetic noise to a competing speech test (MCRM). This suggests that when choosing appropriate outcome measures for auditory training studies, consideration of a compromise between high sensitivity and high test-retest reliability may be warranted.

Objective assessment of cognition

Studies that use objective outcome measures rather than subjective self-report and behavioural measures have the benefits of reducing any participant response or cognitive bias. One novel objective marker is pupil dilation, which has been used as a marker of the cognitive demands of listening in older adults, including those with hearing loss.⁷¹ Kuchinsky et al⁷² demonstrated that the peakedness of the pupil response increased during a word recognition task that was particularly challenging. In a follow-up speech perception training

study,⁴⁴ pupil size measured post-training was larger and peaked more rapidly during a speech perception task. The authors suggested that increased arousal and a possible increase in attentional focus or engagement occurs as a result of training. Other electrophysiological measures, such as alpha waves⁷³ may also be a marker of attention or engagement with a task, and offer a potential measure of changes in the cognitive resources required for listening following auditory training.

What about training cognition directly?

Given that cognition appears to play a critical role in pre-to post auditory training benefits, can training cognition directly offer a more direct route for people with hearing loss? Studies of a commercial working memory training programme (Cogmed RM) have shown generalized post-training improvements for attention and self-report of cognition in younger and older adults,⁷⁴ and speech perception in children with cochlear implants.⁷⁵ To date, there have been no published studies of Cogmed RM in adults with mild-moderate hearing loss.

Our third training study was a registered clinical RCT using Cogmed RM in a sample of 57 existing hearing aid users.⁶⁶ Cogmed RM uses an adaptive paradigm for the trained group and a fixed three-item span paradigm for the active control group, which allowed blinding of both the participants and the researchers. The results, not yet published, showed that there was near-transfer for an untrained working memory task but no far-transfer to a cognitively 2-competing talker speech perception task (informational masking). These results are broadly consistent with the cognitive neuroscience literature. A systematic review of 52 cognitive training studies⁶² showed statistically significant differences for those undergoing cognitive training compared to control groups, with small and moderate effect sizes for nonverbal and verbal memory, working memory and processing speed. However, there were no significant

effects seen for executive function and attention, indicating no generalization to the broader underlying cognitive constructs.⁷⁶ It has been suggested that working memory training enhances working memory tasks that have a similar underlying cognitive construct and share similar structural features.⁷⁷ It may well be that training-related improvements in working memory are mediated by specific strategies that are employed by participants, such as chunking or grouping.⁷⁸

Where to next?

The evidence is clear that people improve on what they train on, whether the training stimuli are auditory or cognitive. Generalisation of learning to untrained tasks is more uncertain, although more likely to occur for near-transfer than far-transfer. A theme that seems to be coming to the fore is the role of cognition in auditory training, specifically executive processes such as attention switching and updating of memory. These are processes that are integral for successful listening in challenging or adverse conditions, therefore training stimuli that engage these processes may well be the key to providing benefits from training programs.

To optimise the benefits of training to everyday real-world communication, we propose that an integrated auditory-cognitive approach is taken. Training would, for example, target the cognitive processes that underpin speech perception *within* speech tasks rather than directly training cognition that is far-removed from speech perception, or speech in noise perception that has limited cognitive involvement (e.g. uses energetic masking).

Reviewing the unanswered questions posed in Table 2, there appears to be some headway made in addressing questions a-c. Training parameters in auditory stimuli that engage executive processes rather than cognitive training in isolation may provide greater real world

benefits. The benefits of auditory training may be best demonstrated if outcome measures are appropriate and sensitive to the underlying mechanisms of benefit, such as those that underpin executive processes. Further research is needed to specifically address these hypotheses, and of course, many questions remain unanswered.

Returning to the main problem that many people with hearing loss experience, that of listening to speech in background noise. A holistic rehabilitative approach that aims to reduce activity limitations and participation restrictions has been suggested by Arthur Boothroyd.²⁵ We would like to propose that for rehabilitation, auditory training is expanded to target both listening and communication abilities through appropriately designed training programs that enhance cognition, specifically executive processes. Furthermore, this training should be delivered in a way that promotes both intrinsic and extrinsic motivations of the user in order to enhance enjoyment and adherence. This type of approach would be best considered in conjunction with hearing aids and management strategies outside of the scope of this article. Such strategies may include individualised educational programs that encourage active engagement of the patient with educational materials to enhance knowledge of hearing loss, hearing aids and effective communication,⁷⁹⁻⁸¹ appropriate setting of expectations, patient motivations, and shared goal-setting,⁸² alongside the active inclusion of patients' communication partners.⁸³

Finally, with the increasing use of the internet and smartphone technologies, even in older people,⁸⁴ and the growing interest in the concept of tele-audiology, auditory-cognitive training is ideally suited for online delivery that can be tailored to meet an individual's needs, can be easily accessed when needed, with increased gameplay and interaction elements, and

delivered alongside other hearing management strategies.⁸⁵ But that's another story, for another day.

References

1. Davis A, Smith P, Ferguson M, Stephens D, Gianopoulos I. Acceptability, Benefit and Costs of Early Screening for Hearing Disability: a Study of Potential Screening Tests and Models. *Health Technology Assessment*. 2007;11(42):1-294.
2. Lin FR, Metter EJ, O'Brien RJ, Resnick SM, Zonderman AB, Ferrucci L. Hearing Loss and Incident Dementia. *Archives of Neurology*. 2011;68(2):214-220.
3. Lin F, Ferrucci L, An Y, et al. Association of Hearing Impairment with Brain Volume Changes in Older Adults. *NeuroImage*. 2014;90:84-92.
4. Boothroyd A. Adapting to Changed Hearing: The Potential Role of Formal Training. *Journal of the American Academy of Audiology*. 2010;21(9):601–611.
5. Pichora-Fuller MK, Singh G. Effects of Age on Auditory and Cognitive Processing: Implications for Hearing Aid Fitting and Audiologic Rehabilitation. *Trends in Amplification*. 2006;10(1):29-59.
6. Tun PA, Williams VA, Small BJ, Hafter ER. The Effects of Aging on Auditory Processing and Cognition. *American Journal of Audiology*. 2012;21(2):344-350.
7. Akeroyd MA. Are individual differences in speech reception related to individual differences in cognitive ability? A survey of twenty experimental studies with normal and hearing-impaired adults. *International Journal of Audiology*. 2008;47(Suppl 2):S53-71.
8. Shinn-Cunningham BG, Best V. Selective Attention in Normal and Impaired Hearing. *Trends in Amplification*. 2008;12(4):283-299.
9. Moore DR, Edmondson-Jones M, Dawes P, et al. Relation between Speech-in-Noise Threshold, Hearing Loss and Cognition from 40–69 Years of Age. *PloS One*. 2014;9(9):e107720.

10. Kiessling J, Pichora-Fuller MK, Gatehouse S, et al. Candidature For and Delivery of Audiological Services: Special Needs of Older People. *International Journal of Audiology*. 2003;42(Suppl 2):S92-101.
11. WHO. *International Classification of Functioning, Disability and Health: ICF*. Geneva: WHO;2001.
12. Sweetow RW, Henderson Sabes J. The Need for and Development of an Adaptive Listening and Communication Enhancement (LACE) Program. *Journal of the American Academy of Audiology*. 2006;17(8):538-558.
13. Anderson S, White-Schwoch T, Parbery-Clark A, Kraus N. A Dynamic Auditory-Cognitive System Supports Speech-In-Noise Perception in Older Adults. *Hearing Research*. 2013;300:18-32.
14. de Boer J, Thornton ARD. Neural Correlates of Perceptual Learning in the Auditory Brainstem: Efferent Activity Predicts and Reflects Improvement at a Speech-in-Noise Discrimination Task. *The Journal of Neuroscience*. 2008;28(19):4929-4937.
15. Tremblay KL, Billings CJ, Friesen LM, Souza PE. Neural Representation of Amplified Speech Sounds. *Ear & Hearing*. 2006;27(2):93-103.
16. Lunner T. Cognitive Function in Relation to Hearing Aid Use. *International Journal of Audiology*. 2003;42(Suppl 1):S49-58.
17. Gatehouse S, Naylor G, Elberling C. Benefits From Hearing Aids in Relation to the Interaction Between the User and the Environment. *International Journal of Audiology*. 2003;42 (Suppl 1):S77-85.
18. Lunner T, Sundewall-Thorén E. Interactions Between Cognition, Compression, and Listening Conditions: Effects on Speech-In-Noise Performance in a Two-Channel Hearing Aid. *Journal of the American Academy of Audiology*. 2007;18(7):604-617.

19. Sarampalis A, Kalluri S, Edwards B, Hafter E. Objective Measures of Listening Effort: Effects of Background Noise and Noise Reduction. *Journal of Speech, Language and Hearing Research*. 2009;52(5):1230-1240.
20. Chisolm TH, Johnson CE, Danhauer JL, et al. A Systematic Review of Health-Related Quality of Life and Hearing Aids: Final Report of the American Academy of Audiology Task Force on the Health-Related Quality of Life Benefits of Amplification in Adults. *Journal of the American Academy of Audiology*. 2007;18(2):151-183.
21. Kochkin S. MarkeTrak VIII: Consumer Satisfaction with Hearing Aids is Slowly Increasing. *The Hearing Journal*. 2010;63(1):19-20.
22. Johnson EE, Dillon H. A Comparison of Gain for Adults from Generic Hearing Aid Prescriptive Methods: Impacts on Predicted Loudness, Frequency Bandwidth, and Speech Intelligibility. *Journal of the American Academy of Audiology*. 2011;22(7):441-459.
23. Dubno JR. Benefits of Auditory Training for Aided Listening by Older Adults. *American Journal of Audiology*. 2013;22(2):335-338.
24. World Health Organization. Deafness and hearing impairment. 2015; <http://www.who.int/mediacentre/factsheets/fs300/en/>. Accessed 14th April 2015.
25. Boothroyd A. Adult Aural Rehabilitation: What Is It and Does It Work? *Trends in Amplification*. 2007;11(2):63-71.
26. Bamford J. Auditory Training What Is It, What Is It Supposed To Do, and Does It Do It? *British Journal of Audiology*. 1981;15:75-78.
27. Kricos PB, McCarthy P. From Ear to There: A Historical Perspective on Auditory Training. *Seminars in Hearing*. 2007;28(2):89-98.

28. Pichora-Fuller MK, Levitt H. Speech Comprehension Training and Auditory and Cognitive Processing in Older Adults. *American Journal of Audiology*. 2012;21(2):351-357.
29. Moore DR, Amitay S. Auditory training: Rules and Applications. *Seminars in Hearing*. 2007;28(2):99-109.
30. Moore DR, Halliday LF, Amitay S. Use of Auditory Learning to Manage Listening Problems in Children. *Philosophical Transactions of the Royal Society B: Biological Sciences*. 2009;364(1515):409-420.
31. Tremblay K. Training-Related Changes in the Brain: Evidence From Human Auditory-Evoked Potentials. *Seminars in Hearing*. 2007;28(2):120-132.
32. Anderson S, Kraus N. Auditory Training: Evidence for Neural Plasticity in Older Adults. *SIG 6 Perspectives on Hearing and Hearing Disorders: Research and Diagnostics*. 2013;17(1):37-57.
33. Pizarek R, Shafiro V, McCarthy P. Effect of Computerized Auditory Training on Speech Perception of Adults With Hearing Impairment. *SIG 7 Perspectives on Aural Rehabilitation and Its Instrumentation*. 2013;20(3):91-106.
34. Zhang M, Miller A, Campbell MM. Overview of Nine Computerized, Home-Based Auditory-Training Programs for Adult Cochlear Implant Recipients. *Journal of the American Academy of Audiology*. 2014;25(4):405-413.
35. Sweetow RW, Palmer CV. Efficacy of Individual Auditory Training in Adults: A Systematic Review of the Evidence. *Journal of the American Academy of Audiology*. 2005;16(7):494-504.
36. Henshaw H, Ferguson MA. Efficacy of Individual Computer-Based Auditory Training for People with Hearing Loss: A Systematic Review of the Evidence. *PLoS One*. 2013;8(5):e62836.

37. Wong LL, Hickson L. *Evidence-Based Practice in Audiology: Evaluating Interventions for Children and Adults with Hearing Impairment*. Plural Publishing; 2012.
38. Stacey PC, Raine CH, O'Donoghue GM, Tapper L, Twomey T, Summerfield AQ. Effectiveness of Computer-Based Auditory Training for Adult Users of Cochlear Implants. *International Journal of Audiology*. 2010;49(5):347-356.
39. Rencanzone G, Schreiner C, Merzenich M. Plasticity in the Frequency Representation of Primary Auditory Cortex Following Discrimination Training in Adult Owl Monkeys. *Journal of Neuroscience*. 1993;13(1):87-103.
40. Ingvalson EM, Lee B, Fiebig P, Wong PC. The Effects of Short-Term Computerized Speech-In-Noise Training on Postlingually Deafened Adult Cochlear Implant Recipients. *Journal of Speech, Language, and Hearing Research*. 2013;56(1):81-88.
41. Chisolm T, Arnold M. Evidence About the Effectiveness of Aural Rehabilitation Programs for Adults. In: Wong L, Hickson L, eds. *Evidence-Based Practice in Audiology*. San Diego: Plural Publishing; 2012.
42. Anderson S, White-Schwoch T, Parbery-Clark A, Kraus N. Reversal of Age-Related Neural Timing Delays With Training. *Proceedings of the National Academy of Sciences*. 2013;110(11):4357-4362.
43. Ferguson MA, Henshaw H, Clark D, Moore D. Benefits of Phoneme Discrimination Training in a Randomized Controlled Trial of 50–74 Year Olds With Mild Hearing Loss. *Ear & Hearing*. 2014;35(4):e110-121.
44. Kuchinsky SE, Ahlstrom JB, Cute SL, Humes LE, Dubno JR, Eckert MA. Speech-Perception Training for Older Adults with Hearing Loss Impacts Word Recognition and Effort. *Psychophysiology*. 2014;51(10):1046-1057.

45. Barker F, Mackenzie E, Elliott L, Jones S, de Lusignan S. Interventions to Improve Hearing Aid Use in Adult Auditory Rehabilitation. *The Cochrane Library*. 2014.
46. Brown DJ, Proulx MJ. Increased Signal Complexity Improves the Breadth of Generalization in Auditory Perceptual Learning. *Neural plasticity*. 2013;2013:879047.
47. Schumann A, Serman M, Gefeller O, Hoppe U. Computer-Based Auditory Phoneme Discrimination Training Improves Speech Recognition in Noise in Experienced Adult Cochlear Implant Listeners. *International Journal of Audiology*. 2015;54(3):190-198.
48. Burk MH, Humes LE, Amos NE, Strauser LE. Effect of Training on Word-Recognition Performance in Noise for Young Normal-Hearing and Older Hearing-Impaired Listeners. *Ear & Hearing*. 2006;27(3):263-278.
49. Dimatteo MR, Giordani PJ, Lepper HS, Croghan TW. Patient Adherence and Medical Treatment Outcomes: A Meta-Analysis. *Medical Care*. 2002;40(9):794-811.
50. Chisolm TH, Saunders GH, Frederick MT, McArdle RA, Smith SL, Wilson RH. Learning to Listen Again: The Role of Compliance in Auditory Training for Adults with Hearing Loss. *American Journal of Audiology*. 2013;22(2):339-342.
51. Sweetow RW, Henderson Sabes J. Auditory Training and Challenges Associated with Participation and Compliance. *Journal of the American Academy of Audiology*. 2010;21(9):586-593.
52. Deci E, Ryan R. Intrinsic Motivation and Self-Regulation in Human Behavior. *New York: Plenum Press*. 1985.
53. Bavelier D, Davidson RJ. Games To Do You Good: Neuroscientists Should Help to Develop Compelling Videogames That Boost Brain Function and Improve Well-Being. *Nature*. 2013;494:425-426.
54. Ferguson M, Henshaw H. Auditory Training as an Intervention For Adults With Hearing Loss; The Current State of Play. *ENT and Audiology News*. 2011;20(1).

55. Sedgwick P. Clinical Significance Versus Statistical Significance. *BMJ*. 2014;348:g2130.
56. Cohen J. *Statistical Power Analysis For The Behavioral Sciences (2nd Ed.)*. Hillsdale, NJ: Lawrence Earlbaum Associates; 1988.
57. Humes LE. Individual Differences Research and Hearing Aid Outcomes. *Seminars in Hearing*. 2013;34(02):67-73.
58. Gatehouse S. Rehabilitation: Identification of Needs, Priorities and Expectations, and the Evaluation of Benefit. *International Journal of Audiology*. 2003;42 Suppl 2:2S77-83.
59. Gatehouse S, Noble W. The Speech, Spatial and Qualities of Hearing Scale (SSQ). *International Journal of Audiology*. 2004;43:85-99.
60. Chan RCK, Shum D, Touloupoulou T, Chen EYH. Assessment of Executive Functions: Review of Instruments and Identification of Critical Issues. *Archives of Clinical Neuropsychology*. 2008;23(2):201-216.
61. Henshaw H, McCormack A, Ferguson MA. Intrinsic and Extrinsic Motivation Drives Computer-Based Auditory Training Uptake, Engagement, and Adherence for People with Hearing Loss. *Frontiers in Psychology*. in press.
62. Lampit A, Hallock H, Valenzuela M. Computerized Cognitive Training in Cognitively Healthy Older Adults: A Systematic Review and Meta-Analysis of Effect Modifiers. *PLoS medicine*. 2014;11(11):e1001756.
63. Song JH, Skoe E, Banai K, Kraus N. Training to Improve Hearing Speech in Noise: Biological Mechanisms. *Cerebral Cortex*. 2011;22(5):1180-1190.
64. Anderson S, White-Schwoch T, Choi HJ, Kraus N. Training Changes Processing of Speech Cues in Older Adults with Hearing Loss. *Frontiers in Systems Neuroscience*. 2013;7(97).

65. Henshaw H, Ferguson MA. Assessing the Benefits of Auditory Training to Real-World Listening: Identifying Appropriate and Sensitive Outcomes. . Paper presented at: Proceedings of ISAAR 2013: Auditory Plasticity - Listening with the Brain. 4th Symposium on Auditory and Audiological Research 2014; Nyborg, Denmark.
66. Henshaw H, Ferguson MA. Working Memory Training for Adult Hearing Aid Users: Study Protocol for a Double-Blind Randomized Active Controlled Trial. *Trials*. 2013;14(1):417.
67. Ferguson MA, Henshaw H. Auditory Training Can Improve Working Memory, Attention and Communication in Adverse Conditions for Adults With Hearing Loss. *Frontiers in Psychology* .2015; 6: article 556..
68. Owen AM, Hampshire A, Grahn JA, et al. Putting Brain Training To The Test. *Nature*. 2010;465:775-778.
69. Shinn-Cunningham BG. Object-Based Auditory and Visual Attention. *Trends in Cognitive Sciences*. 2008;12(5):182-186.
70. Howard CS, Munro KJ, Plack CJ. Listening Effort At Signal-To-Noise Ratios That Are typical Of The School Classroom. *International Journal of Audiology*. 2010;49(12):928-932.
71. Zekveld AA, Kramer SE, Festen JM. Cognitive Load During Speech Perception in Noise: The Influence of Age, Hearing Loss, and Cognition on the Pupil Response. *Ear & hearing*. 2011;32(4):498-510.
72. Kuchinsky SE, Ahlstrom JB, Vaden KI, et al. Pupil Size Varies With Word Listening And Response Selection Difficulty In Older Adults With Hearing Loss. *Psychophysiology*. 2013;50(1):23-34.

73. Petersen EB, Wöstmann M, Obleser J, Stenfelt S, Lunner T. Hearing Loss Impacts Neural Alpha Oscillations Under Adverse Listening Conditions. *Frontiers in Psychology*. 2015;6:177.
74. Brehmer Y, Westerberg H, Backman L. Working-Memory Training in Younger and Older Adults: Training Gains, Transfer, and Maintenance. *Frontiers in Human Neuroscience* 2012;6(63):1-7.
75. Kronenberger WG, Pisoni DB, Henning SC, Colson BG, Hazzard LM. Working Memory Training for Children with Cochlear Implants: A Pilot Study. *Journal of Speech, Language, and Hearing Research*. 2011;54(4):1182-1196.
76. Melby-Lervag M, Hulme C. Is Working Memory Training Effective? A Meta-Analytic Review. *Developmental Psychology*. 2013;49(2):270-291.
77. Thompson TW, Waskom ML, Garel KA, et al. Failure of Working Memory Training to Enhance Cognition or Intelligence. *PLoS One*. 2013;8(5):e63614.
78. Dunning DL, Holmes J. Does Working Memory Training Promote the Use of Strategies on Untrained Working Memory Tasks? *Memory & Cognition*. 2014;42(6):854-862.
79. Ferguson M, Brandreth M, Leighton P, Brassington W, Wharrad H. A Randomised Controlled Trial to Evaluate the Benefits of a Multimedia Educational Programme for First-Time Hearing Aid Users. *Ear & Hearing*. Accepted.
80. Thorén ES, Öberg M, Wänström G, Andersson G, Lunner T. A Randomized Controlled Trial Evaluating the Effects of Online Rehabilitative Intervention for Adult Hearing-Aid Users. *International Journal of Audiology*. 2013;53(7):452-461.
81. Hickson L, Worrall L, Scarinci N. A Randomized Controlled Trial Evaluating the Active Communication Education Program for Older People with Hearing Impairment. *Ear & Hearing*. 2007;28(2):212-230.

82. Laplante-Levesque A, Hickson L, Worrall L. A Qualitative Study of Shared Decision Making in Rehabilitative Audiology. *Journal of the Academy of Rehabilitative Audiology*. 2010;43:27-43.
83. Kamil RJ, Lin FR. The Effects of Hearing Impairment in Older Adults on Communication Partners: A Systematic Review. *Journal of the American Academy of Audiology*. 2015;26(2):155-182.
84. Deloitte. The Smartphone Generation Gap: Over 55? There's No App For That. 2014; <http://www2.deloitte.com/content/dam/Deloitte/global/Documents/Technology-Media-Telecommunications/gx-tmt-2014prediction-smartphone.pdf> Accessed 10th December 2014.
85. Ferguson M, Henshaw H. Computer and Internet Interventions to Optimise Listening and Learning for People with Hearing Loss: Accessibility, Use and Adherence. *American Journal of Audiology*. In press.

Figure 1. Mean and 95% confidence intervals dual-task score (maximum value=40) across three speech in noise conditions for existing hearing aid users. Pre- and post-training with phoneme discrimination in noise. T1 and T2 = pre-training, T3 = immediate post-training, T1-T2 = 1 week, T2-T3 = 1 week. *** $p = .001$

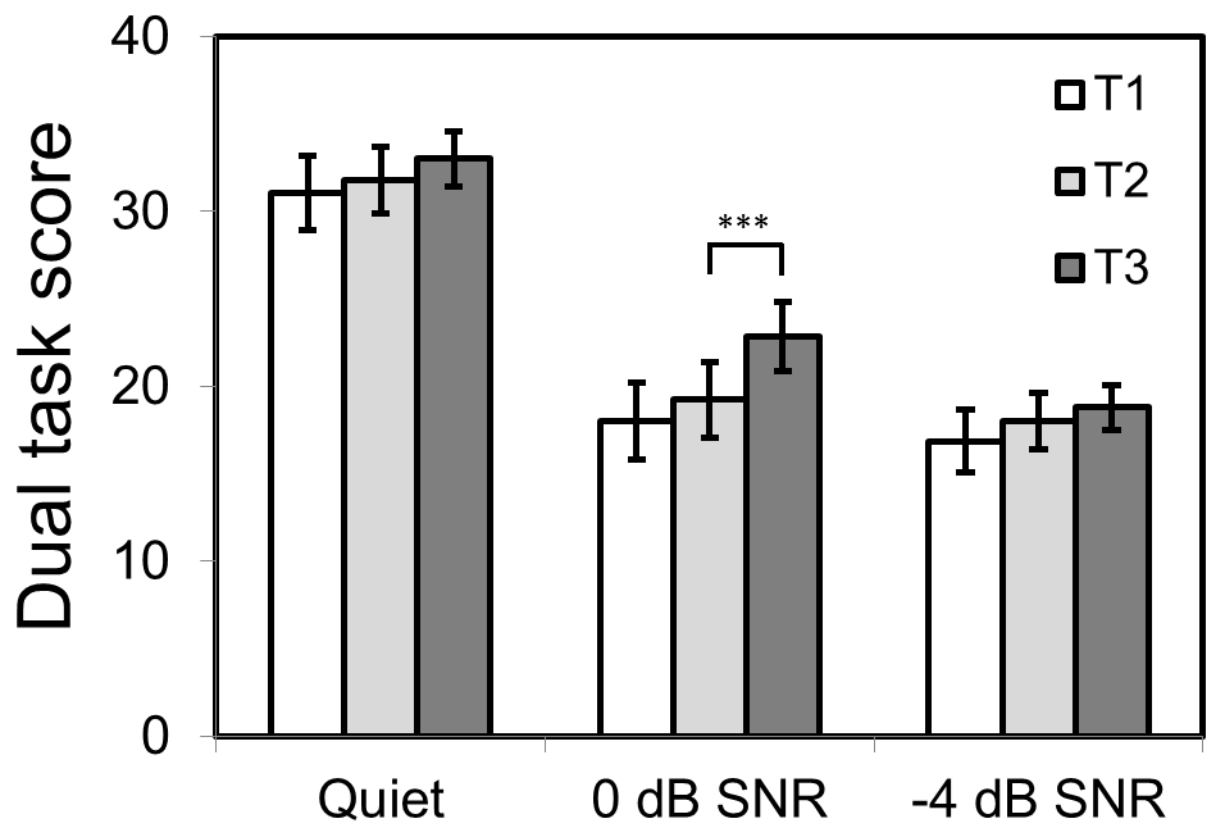


Table 1. Questions on auditory training arising from the literature

- a. What are the optimal training parameters that provide the greatest benefits?
- b. What are the relative benefits of auditory and cognitive training?
- c. What are the optimal outcome measures to measure benefits of auditory training?
- d. What is the optimal duration of training?
- e. What are the long-term effects of training? Is booster training needed?
- f. What factors predict benefits from training in individuals?
- g. What are the motivations underlying adherence, and how can adherence and engagement be improved?
- h. Can auditory training improve acclimatisation in hearing aid and cochlear implant users?

Table 2. Intraclass correlation coefficient (ICC) and 95% confidence intervals (CI) for tests of cognition and speech perception from two auditory training studies. TEA = Test of Everyday Attention. ASL = Adaptive Sentence List, MCRM = Modified Coordinate Response Measure (MCRM).

	ICC	95% CI		P
		lower	upper	
Ferguson et al (2014)⁴³				
Digit span	0.88	0.70	0.95	<0.001
Visual monitoring task: slow (1/2s)	0.70	0.23	0.88	0.007
Visual monitoring task: fast (1/1s)	0.72	0.28	0.89	0.005
TEA single task (#6)	0.93	0.82	0.97	<0.001
TEA dual task (#7)	0.83	0.59	0.93	<0.001
TEA dual-task decrement	0.72	0.30	0.89	0.004
Digit triplet test	0.87	0.66	0.94	<0.001
ASL sentence test	0.67	0.21	0.86	0.007
Henshaw and Ferguson (2014)⁶⁵				
Dual task word repetition (2° task)	0.93	0.85	0.97	< 0.001
Quiet	0.90	0.78	0.96	< 0.001
0 dB	0.80	0.58	0.91	< 0.001
-4 dB	0.35	-3.70	0.69	0.128
Dual task digit recall (1° task)	0.86	0.70	0.94	< 0.001
Quiet	0.81	0.60	0.91	< 0.001
0 dB	0.76	0.49	0.88	< 0.001
-4 dB	0.72	0.41	0.87	0.001
Letter number sequencing task	0.83	0.65	0.92	< 0.001
MCRM threshold	0.45	0.17	0.83	0.063