

The brain's habit of rewiring itself takes time, an important concern in good fittings.

HABRAT: Hearing Aid Brain Rewiring Accommodation Time

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Every practicing dispenser knows that it may take a considerable amount of time for the listener to "get used to" new hearing aids. But do fundamental and beneficial changes in the wiring of the brain itself help the auditory rehabilitation process? Data presented here indicate it is sometimes impossible to properly evaluate the benefit of a particular hearing aid fitting for weeks or even months, which in turn implies that extraordinary judgment is required when the "wear it awhile and you'll get used to it" vs. "let me readjust the hearing aid" decision must be made by the dispenser.

We illustrate some of the issues in a light-hearted vein with the following conversation:

Suspicious Customer: How long do I have to wear my new hearing aids before I get used to them?

Dr. Abonso: That's a tough question. Often, your new hearing aids will sound wonderful the instant you put them on.

S.C.: Well, mine didn't; they still sound funny after three weeks.

Dr. Abonso: From listening to your speech, I suspect that you have a severe high frequency loss and that you haven't heard many of the high frequency speech sounds for years.

S.C.: Who are you, Professor Higgins or somebody? What can you tell from my speech?

Dr. Abonso: Your "S's" sound mushy, for one thing. People who hear clearly usually don't make mushy "S" sounds.

S.C.: But you haven't even asked why I'm unhappy with my hearing aids.

Dr. Abonso: Tell me your complaints.

S.C.: I have three. First, everyone sounds a bit like Donald Duck, even me. Second, my own voice bothers me because it also sounds as though I'm speaking into



cartoon by Fred Waldhauer

Suspicious customer questions wise Dr. Abonso.

a barrel. Third, the hearing aid is noisy; unless I'm in a very quiet room, I hear all sorts of distracting noises.

Dr. Abonso: One of those, the barrel effect, your dispenser can probably improve (but perhaps not eliminate) with a modification. The other two sound like a problem of retraining your brain.

S.C.: Why bring my brain into this? It's my hearing that is impaired.

Dr. Abonso: Because your brain is designed to be moldable, like plastic. If one has a stroke, for example, another part of the brain can ultimately take over the tasks the damaged part was doing.

S.C.: What's that have to do with me?

Dr. Abonso: When you lose part of your hearing, the corresponding part of your brain—which now has no input from your ear—apparently gets "rewired" to do other things. May I tell you about some recent research?

S.C.: If you have to. I was hoping for a simple conversation I could understand.

Dr. Abonso: Prof. Gatehouse in Scotland has been studying how long it takes for the brain to make use of new information from a hearing aid. It looks as though the brain makes little use of the new information for five to six weeks, then gradually starts to use it.

S.C.: How does he know?

Dr. Abonso: He measured word recognition scores every week. The scores didn't change for 5 weeks, but after 6 weeks they climbed steadily.

S.C.: So I'll be happy with my hearing aids in another 3-6 weeks?

Dr. Abonso: Maybe, maybe not. Before going through that much unhappiness, it would be a good thing to have your dispenser do a "real ear" measurement to make absolutely certain your hearing aids are giving you the right amount of high frequency gain. Perhaps they need to be readjusted.

S.C.: So after my hearing aids have been readjusted, I'll be happy in 3-6 more weeks and not toss them into my dresser drawer?

Dr. Abonso: Unless the problem is that the hearing aids are painfully loud or are distorted and sound rotten. You might get used to that in time, but you would never be able to hear very well in noise. Your dispenser might want to do a listening check to make certain your aids produce a clear, undistorted sound.

S.C.: This sounds tricky. You mean sometimes the aids need readjustment, sometimes it is only my brain that needs readjustment.

Dr. Abonso: Well put.

S.C.: Where can I find someone competent to help me decide which is which?

Dr. Abonso: Well. . .

Accommodation

In keeping with the wisdom of the mythical Dr. Abonso, we present an unproven but likely argument that more is going on in the accommodation process than we usually think. Our usual explanations—familiarization with a new device, acceptance of the changed quality of sounds and a reorientation to the more completely heard (and sometimes confusing) auditory world bring to mind some sort of simple learning process. These may well miss the most important component: gradual changes in the brain itself.

Thus, while it will not seem at all strange for dispensers to hear that hearing-impaired listeners require a period of time to accommodate to the characteristics of their hearing aids, we aim to make a qualitatively different argument, with fundamental implications for the fitting and adjustment of hearing aids. What we

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Accommodation time

put forward is actually nothing new, as the first report of the phenomenon was made over 50 years ago.¹¹ Rather than exhibiting mere "getting used" to the hearing aid, we argue that there is a fundamental perceptual process whereby a hearing-impaired listener, when presented with a range of speech information which had been previously unavailable, can take considerable time to learn to make optimum use of the new set of speech cues and thereby derive optimal benefit from the amplification.

Although the data of Watson and Knudsen lay dormant for some years, there has been a more recent theoretical consideration of their implications.¹ Most recently, Gatehouse⁵ has shown that the benefits of amplification as measured by speech-identification ability in noise, although initially stable, can continue to increase following experience with the amplified signal over a period of some six to 12 weeks, in ways that cannot be interpreted as merely test learning effects. Fig. 1 shows some of those data.

Note that the benefits of a hearing aid characteristic which would be regarded as theoretically superior to a competitor (in this case, a rising frequency response versus a flat frequency response), could not be determined initially. The real benefit only started to become apparent after some four to six weeks' experience with the particular amplification characteristic.

Fig. 2 shows data from further experiments.⁶ Here, individuals whose regular hearing aids had little output above 2.5 kHz were given the potential benefits of previously unavailable high frequency information. Here, again, the presumed benefits did not appear on initial testing; they were realized after time. Other recent data⁴ also show both the *perceived* benefits of amplification and *measured* speech identification abilities can increase across a three-month time period.

To be fair, there is some evidence to the contrary in the Bentler et al study,² where a group of 65 hearing aid users were followed for 12 months after hearing aid fitting. Here no consistent trends were observed. Taken together, however, we have growing evidence for some process in which new information may not be utilized optimally when it is first available but where the auditory system can change its ability to utilize the pattern of speech cues presented to it.

Given this growing body of evidence, we are now faced with the challenge of explaining these underlying processes and taking them into account in audiological practice.

What going on in the brain?

At this stage in our knowledge it is not possible to identify with any degree of

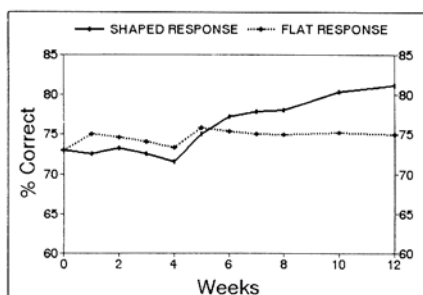


Fig. 1. Speech-identification-in-noise scores from Gatehouse⁵ in the fitted ears for flat amplification and a rising frequency response.

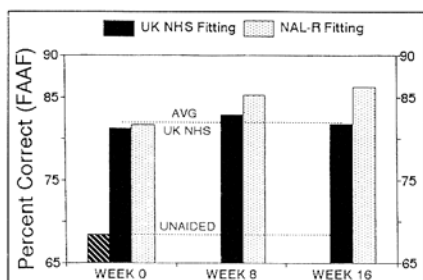


Fig. 2. Speech-identification-in-noise scores from Gatehouse⁶ as a function of time after conversion from the "narrow-band" response (UK NHS) to the "wider-band" condition (NAL-R).

certainly the underlying basis behind the experimental finding that the auditory system does appear to require time to accommodate the pattern of speech cues available to it.

From literature outside the audiological domain, however, we may be able to make some educated presumptions. In neurophysiology and neuropsychology, there has been a growing interest in cortical plasticity, which challenges the widely held view that in developed systems (as opposed to those undergoing maturation) the cortical representation of sensory events remains relatively fixed. The growing body of evidence lies predominantly in the visual and somatosensory domains.

Following retinal damage, for example, the corresponding reception area of the visual cortex does not respond to any visual stimulus. With the passage of time, however, the "empty" cortex area begins to respond to stimulation from outside the damaged retinal area.

Similarly, in somatosensory experiments on animals, the loss of a limb or digit is followed by a remapping of the cortical representation of the topography to surrounding digits/limbs. Indeed, the evidence proceeds further, and shows that chronic stimulation of a particular digit or set of digits leads to an expansion of the cortical representation of those digits.

In the auditory domain there is also increasing evidence that cortical plasticity can exist and that the adult brain can learn to remap its resources according to the patterns of acoustical stimulation it receives. In one experiment,⁸ a frequency

region of the cochlea in adult guinea pigs is destroyed, resulting in a cortical remapping of the corresponding area so that it receives signals from the intact adjacent areas of the cochlea. Similarly, Willot et al¹² studied a particular mouse mutant which develops high frequency sensorineural hearing loss in adulthood, resulting in a reallocation of cortical high frequency areas to low frequency areas. Most relevant of all, Recanzone et al⁷ have shown that by instituting a chronic change in the pattern of auditory stimulation through intensive training on a frequency discrimination task, the cortical representation of the "trained" frequencies increases with respect to that for the untrained frequencies, which are now less active. These animal findings are consistent with the hypothesis that the adult brain "rewires" itself as needed to best process incoming signals.

Turning to the human, we also find many examples of the adaptability of the adult brain. With vision, for example, it is possible to take inverting goggles and tape them to your forehead. At first you can't read, you can't write, you stumble around and you certainly can't ride a bicycle. Yet in four to six weeks of constantly wearing these inverting goggles, you become able to do all of those things. The world is back the right way up. When you finally take the goggles off, however, you go through a period of time in which you can't ride a bike, read, write, etc. To all appearances, the visual system has somehow rewired itself. (These goggle experiments, reported by Cohler,³ were motivated by an interest in whether the inverted image on the back of the retina was hardwired to appear to the brain right side up, or if the necessary visual inversion could be learned).

There is an even more powerful visual example reported by Cohler. You can take goggles that distort differently, depending on whether you look to the left or right. So if you are looking at a building of windows, the windows on the left might tilt to the left and the windows on the right tilt to the right (see Fig. 3). Worse, if you look straight ahead and move your head quickly back and forth, the shape of the windows goes through wild gyrations. After several weeks of wearing these funny goggles, however, the windows all look square, and you can shake your head while looking straight and the windows don't move! Your brain can unscramble all of that rapidly varying visual distortion in real time, filtering it out so that everything stands still. (When you first take the goggles off, the windows go through wild gyrations as you move your head back and forth quickly).

A small vignette forms an auditory example from one of the authors (MCK).

"When I was first working on hi-fidelity hearing aids a decade or so ago, I wore a pair of ITE hearing aids with smooth response, but a response that rolled off sharply above 8 kHz. One night, in a fit of enthusiasm, I wore them to bed. The next morning, I had forgotten that I had them on, turned on the shower and was about to step in, when I suddenly realized I was about to ruin two hearing aids. I quickly took them out and all of a sudden heard a very high pitched hiss. It wasn't quite located in my head, but I couldn't find it in the room. I spent two minutes cocking my head listening. Then, suddenly, it swept up to the shower and joined the broad band SSSHHH of the shower. In just a few weeks, I had lost the ability to localize the octave band of sound between 8 and 16 kHz.

"Now it didn't take me months to regain that ability, it was only minutes, but when you have someone who hasn't heard high frequency sounds for several years, experience teaches us that it may take several weeks before that person relearns the task, even if you could give him or her perfect hearing aids."

Brain rewiring

While we have no direct evidence as yet of cortical changes in humans following either sensorineural hearing impairment or the provision of amplification, we suggest that the following process is consistent with our knowledge and understanding: As an individual progressively acquires a high frequency sensorineural hearing loss, the cortical representation of the lower intensity, higher frequency regions of the audible world will no longer receive stimulation.

Because of this lack of stimulation, the brain will begin to allocate surrounding frequencies and intensities to those unstimulated regions. Given that most sensorineural hearing impairments are slowly progressive, this process will occur over a number of years, if not decades.

When the hearing-impaired individual is provided with amplification (and here we presume that the amplification is appropriately designed), then the previously inaudible areas of the auditory world now become audible and are presented to the brain.

However, the areas that were previously used for coding the higher frequency, low intensity signals have now been reallocated to other frequencies and intensities, and it may take a considerable period of time for this re-wiring (unremapping?) to take place. (We give a homely analogy: Having given away all the 4th floor telephone lines to the low frequencies, the brain must first get them back—or find an empty floor with mostly unused lines—before reallocating any to

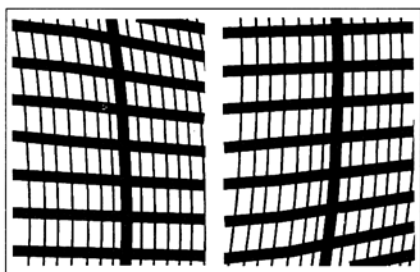


Fig. 3. Approximate left-field and right-field view of windows seen through Cohler's distorting goggles. After several weeks, both views appear square.

the high frequencies.)

How long?

We now have to address the issues of overall timescales. The experimental evidence would suggest that some of these changes can take place over timescales as long as weeks or months. These times are entirely consistent with some of the animal experiments and the human perceptual experiments described above.

Practicing dispensers, however, know that some hearing-impaired listeners gain the benefits of amplification almost immediately. Perhaps the time taken to "re-learn" the high frequency information depends upon how much of the information was absent—and for how long.

In addition, training seems to speed up the process. Walden et al⁹ found that after two weeks of intensive Army aural rehabilitation, their newly hearing-aided subjects improved their word recognition scores about 10%; subjects given an additional 10 days of intensive visual or auditory training improved another 15%. These are much shorter times than shown in Figs. 1 and 2. Finally, once a new wiring is in place, it tends to remain—rusty but available—for months or years. The old hearing aid scores for the subjects in Fig. 2, for example, did not drop over the period of the test, even though the subjects were no longer wearing hearing aids.

Practical implications for dispensers

So what are the implications for practice? Experimental evidence suggests that it can take time for the benefits of the availability of particular speech cues to become apparent, so that comparative trials of different amplification characteristics for some listeners might have to take place across periods of weeks rather than hours or days. This clearly has important implications for the practice of auditory rehabilitation, when there is a question of whether or not the hearing aid characteristics should be adjusted, and it certainly has strong implications for research and evaluation exercises.

This may not be welcome news either to practitioners or researchers, as it is likely to greatly extend the timescales either

of research evaluations or of clinical fitting procedures and programs. But rather than being regarded in its somewhat negative and bothersome light, this can instead be regarded as a positive rehabilitation tool, whereby hearing-impaired listeners can be given a rational basis for the traditional "wear it a while and you'll get used to it," which has been the mainstay of practice since the 1940s.

The danger is that this information may be used as an excuse for inadequate fittings. Indeed, Walden et al¹⁰ found that the largest hearing aid accommodation with time occurred with the poorest hearing aids, and that after sufficient time their subjects scored reasonably well even with "distinctly inappropriate amplification." An information-starved, distortion-inundated brain can do astonishingly well, perhaps explaining the fact that probably 80% of those hearing aids sold in 1991—in both our countries—were narrowband peak-clipping aids. There is some reason to believe that the better the hearing aid, the shorter the accommodation time.

Summary

Our thesis is that the brain is not only an incredibly powerful processor, but that this processor reprograms itself over time to optimize the use of the information that is available to it. The practice of fitting hearing aids (both in selecting adjustments and rehabilitation support) should take this into account. Identifying the factors which govern the degree and speed of accommodation to hearing aids will remain prime areas for research. □

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