So what do the research interests of the Dalai Lama have to do with clinical audiology? There probably aren't too many areas of intersection, but there definitely is one: *brain plasticity*.

The notion of brain plasticity for adults, especially older adults, is a relatively new concept in neuroscience. Today, we know that people like musicians and skilled athletes often have parts of their brain rewired for optimization of a given activity. Even more interesting is evidence suggesting that you might not even have to experience the activity—just thinking about it might alter brain processing. This is where the intersection with the Dalai Lama exists—the University of Wisconsin has a meditation room next to its brain-imaging laboratory.

In the world of audiology, our thoughts about brain plasticity usually relate to the processing of auditory signals, speech understanding, and comprehension. Stuart Gatehouse got us started thinking about all this 20 years ago when he began talking about "auditory acclimatization." Much of his work related to potential changes in brain processing that might occur as a result of the fitting of hearing aids. Brain plasticity, of course, isn't always a positive thing. The unaided ear effect (sometimes called "auditory deprivation") can be a negative plasticity effect when you are fitting bilateral amplification.

We've brought in **Kevin Munro**, PhD, who over the past decade has been involved with several research studies in the area of brain plasticity, the results of which have direct clinical applications.

Dr. Munro is a reader (associate professor) of audiology at the University of Manchester. He also is director of graduate matters in the School of Psychological Sciences. The Manchester Audiology and Deafness Research Group is at the forefront of audiology education and audiologic service delivery in the UK. It's specifically involved in applied research that leads to improved services for hearing-impaired people.

You're probably also familiar with Kevin's publications and presentations on the topics of hearing aid selection, cochlear processing, and pediatric assessment and habilitation. Dr. Munro has been honored for his work with several awards from the British Society of Audiology, of which he is currently vice-chair.

The Dalai Lama suggests that the path to tranquility is daily wisdom. I think you'll find that Kevin's enlightening Page Ten offers an excellent dose of wisdom.

GUS MUELLER
Page Ten Editor

Brain plasticity: There's more to hearing than your ears

By Kevin J. Munro

Kevin J. Munro

1 I have seen some of your articles, and I gather that you think that there are changes in the brain over time that influence how we hear? Have I got that right?

Well, that's pretty close to correct, although it's not quite that simple. One area I've been interested in is commonly referred to as brain plasticity. What this means is that the brain can reorganize as a consequence of changes in the environment. The term is also used by some people when referring to the perceptual consequences of brain reorganization.

2 What exactly do you mean by reorganize?

When we refer to the brain as being plastic or malleable, we mean that the neurons and connections within the brain can be altered. There was a time when we used to think the mature brain did not show these properties, but now we know that both mature and immature brains can change.

A useful analogy for brain plasticity is to think of the brain as a road map covered in roads and roundabouts (or highways and intersections). If you compare your old road map with a more recent one you are likely to see some changes: New highways and intersections may have appeared and some previous ones may have been modified or even disappeared. So, just like road maps, the brain is dynamic, and it is changed by the environment in which it functions. This happens in the auditory and other parts of the brain.

3 I've heard about this plasticity stuff in children, but are you really going to tell me that the brains of adults and elderly people are also plastic?

Well, you might be surprised, but that's exactly what I am saying. It is well known that changes occur during development, but we know that changes can also occur in adults as a result of injury or experience. Think about it: How else can an adult learn a new skill unless their brain is able to change with practice or experience?

4 I know older adults can learn new skills, but isn't this just a result of motivation and lots of practice? What's the proof for brain plasticity?

Before we get to the hearing aspect, let's talk about brain plasticity in general. Some of the most spectacular examples of brain plasticity in adults occur as a result of injury. For example, amputees often report that they continue to experience the sensation of the amputated body parts.

This sensation was given the name "phantom limb" by Silas Weir Mitchell.[1] Mitchell was in charge of a military hospital in Philadelphia during the American Civil War, and it was full of soldiers who had lost limbs from bullet or bayonet injury. He described this in 1871: "*A person in this condition is haunted, as it were, by a … phantom of so much of himself as has been lopped away, an unseen ghost of the lost part.*" Back in those days, it was a puzzle why otherwise lucid and rational men were reporting these sensations.

5 I have heard about phantom limbs, but how do you know this strange perception is a consequence of brain plasticity?

I was just coming to that. Each part of the body is mapped to a specific part of the brain. If you lose a limb, the part of the brain that was previously activated when the limb was touched will start to show activity when a neighboring body part is stimulated. This results in the perception that the missing limb is being stimulated. I think that Yang et al. were probably the first to show a direct link between the perception of phantom limbs and brain plasticity in adult humans using sophisticated brain-imaging techniques.[2]

6 That is pretty spectacular, but do you have any examples that are specific to hearing?

Yes, there is evidence to show that in some profoundly deaf people, the unused hearing part of the brain is activated by visual stimuli. Likewise, in some people who are blind, the unused visual part of the brain is activated by sound. This is called "cross-modal plasticity," and it may explain some of the variability in outcome in individuals who receive a cochlear implant. If the hearing part of the brain responds to visual stimuli before implantation, then it may be hard to reverse this and these implantees may receive less benefit than someone who does not have cross-modal plasticity. You can think of this as having "squatters" in the brain. Once they have moved into the hearing part of your brain, it can be pretty hard to get them to leave.

7 This all sounds interesting, but what about people who are not profoundly deaf? Is there also evidence of plasticity for people with less severe hearing loss?

As I guess you know, we have done some work in this area, and most of our findings were included in a tutorial published a few years ago.[3] One of the first studies we did was to look at changes in performance on a speech-recognition test, over time, in adults with age-related hearing impairment who were fitted with a hearing aid for the first time.[4]

Actually, most of our studies have used these sorts of participants, so we are not talking about especially young brains! Also, we did not provide any particular training: The audiologists just did their normal hearing aid fitting and counseling. We were able to demonstrate that performance improved over time. Before you ask, we had a control condition, and it didn't show improvements over time. So, we know that the changes were not simply an improvement due to practice with the test material.

8 Are you talking about "auditory acclimatization"?

Yes, the late Stuart Gatehouse was the first person to use this term when referring to an improvement in auditory abilities, over time, in adults.[5] The more general term is "perceptual learning." Stuart showed irrefutable changes in several auditory abilities over time in new elderly hearing aid users.

9 Isn't that last sentence a bit controversial? If I recall correctly, many studies have failed to show significant improvements in performance over time.

That's a very good point. Let me start by reiterating that we know that changes in the sensory environment, as a result of deprivation or stimulation, will modify our experience of the world, and this can lead to experience-related or learning-induced reorganization of the brain. We also know that hearing aids, if fitted appropriately, change the sensory input (they make quiet sounds audible and audible sounds louder), and this modifies our experience of the acoustic world. Therefore, it would not be surprising if we were to observe changes in brain and behavioral responses to sound over time. However, you are correct to point out that many studies, including some of our own, have not always shown these expected changes.

10 How do you explain that?

Well, in our study, we measured performance when listening to quiet, average, and raised speech. The biggest improvements over time occurred for the raised speech input, but we didn't see any change for the quiet input. This tells us that there is something important about the presentation level of the speech.

Our explanation is that when quiet speech is amplified, the sound level in the ear canal may still fall within the range of listening levels for the person before using the hearing aid, i.e., listening to quiet speech with the hearing aid is a bit like listening to average speech before using the hearing aid. Since this test condition is not so different from what happened before wearing the hearing aid, there was no need for the brain to reorganize. Therefore, it is not surprising that we didn't see any changes over time. However, if speech is amplified to a new and higher level than the person previously experienced, then this is the condition where one may expect to see changes in performance.

11 Do you think these changes matter to the hearing aid user?

That's an excellent question, but I can't give you a definitive answer. I understand why you're asking, as it's good to know when you should measure benefit for speech understanding. Should you do it at the time of the fitting or wait for acclimatization? While there is irrefutable evidence that changes can occur over time in the laboratory, it is not always clear if these changes have significance in the real world. No acclimatization study has been carried out over a long enough period for us to know the best time to measure outcome.

For the purposes of clinical trials, most researchers allow about 4 weeks, but this is not based on evidence about the time course of brain reorganization. In fact, Gatehouse showed that the acclimatization effect was just starting to occur after 4 weeks of hearing aid use and there was no sign of it reaching a plateau when the study ended after 12 weeks.[6]

I might just add that I have heard some people say that auditory acclimatization occurs only at high frequencies. I don't think this is correct; acclimatization can occur at any frequency that is changed by the hearing aid. In fact, I suspect it will also occur in normal-hearing people if we stimulate or deprive their auditory system. Maybe we can talk about that later.

The important point is that the brain is dynamic and will respond to any significant changes in the acoustic environment. Of course, don't forget that there are many factors, in addition to brain reorganization, to consider in deciding when to measure hearing aid benefit.

12 Like what, for example?

You need to allow time for the person to adjust to incorporating hearing aid use into daily life. This includes becoming competent and confident at fitting the device, manipulating the controls, changing programs, etc.

Also, the expectations of the individual may change over time. For example, if I fit a hearing aid, tell the person that it will be great, and let them listen to speech in a quiet background, I would be surprised if the person didn't report being very satisfied and receiving lots of benefit. If I wait until the person has experienced the full range of listening environments that can occur in every day life, they may be less impressed. You need to avoid this "halo" or "honeymoon" period.

13 Okay, I understand what you're saying. Tell me, apart from speech recognition, have you seen changes in any other auditory abilities?

Yes, we have also seen changes in loudness discomfort level (LDL).[7] In most of our studies, we have measured LDLs in adults with age-related hearing impairment who have been wearing a hearing aid in only one ear. The results show that the LDLs are similar in both ears before the adults use the one hearing aid, but after hearing aid experience they tend to become more tolerant of loud sounds in the ear that has had the hearing aid. So, for example, the LDL for a 1000-Hz tone may be 90 dB HL in both ears before hearing aid use but increase to 95 dB HL in the ear that has been stimulated by the hearing aid.

14 What about the studies I've seen that show no change in LDL in hearing aid users?

As you say, there have been studies that have shown no or only very small changes after hearing aid experience. I have two comments. First, I am saying that it is possible to measure these changes in the laboratory, but I don't yet know if they are big enough to make a difference to the hearing aid fitting. Second, our most recent study doesn't appear to show changes in adults who wear bilateral hearing aids.[8] This may mean that it is the asymmetry caused by using one hearing aid that drives the reorganization. We'll need to do more work in this area to help unravel these findings.

15 So far you have mentioned studies that have shown changes for a couple of behavioral measures. But how do you really know that this is due to brain plasticity?

I think what you are asking is how do we know that these perceptual changes are the consequence of brain reorganization when we haven't carried out physiologic measures related to changes on the brain.

A couple of our studies are relevant here. In one of them, we showed changes in the auditory brainstem response (ABR) in adult hearing aid users.[9] We found in our study that the amplitude of the ABR was greater in ears that had been aided than in ears, with the same degree of hearing impairment, that had not been aided. This suggests that the use of amplification had somehow changed the brain. We don't know if this change was due to more neurons being activated or better synchronization of existing neurons, because either would result in a bigger response.

16 That's interesting. What was the other study you were going to mention?

In that study, we measured the middle ear muscle reflex threshold.[10] We showed that the threshold of the middle ear reflex was higher in ears that had been aided. It has taken a long time for people to accept that the highest level in the adult brain, called the cortex, is plastic, yet these two studies are saying that plasticity can be measured at quite low levels in the pathway. Of course, it might be that descending highways from the brain influence what happens at the lower brainstem level. Regardless of the explanation, we have demonstrated the effect of sensory experience on processing in the adult brain.

17 You mentioned earlier that you think changes also will occur to the auditory system of normal-hearing people if the environment is changed?

I did say that and, yes, we've conducted some research on this topic too. We have done quite a lot of work with normal-hearing people who wear an earplug in one ear continuously for a week. The earplug, of course, causes a temporary auditory deprivation, and previous research had shown that this modifies loudness perception.[11] However, it was not known if this was due to brain reorganization. Our work has shown that the acoustic reflex could be activated with a lower sound level in the ear after it has been plugged and deprived of input.[12] This is consistent with a change in central "gain" and may potentially help to explain tinnitus and/or hyperacusis.

18 Hyperacusis and "central gain"? I could use a quick review of these terms.

No problem. Hyperacusis is commonly defined as an intolerance for

sound levels that are normally judged to be comfortably loud. People with hyperacusis often complain of tinnitus too, so it is assumed that there may be a common mechanism. This is usually considered to be an "abnormal central gain." Essentially, neurons send signals to the brain in response to a sound. A stronger signal generates more firing of the neurons. If a sound generates more neural firing than it should, this may result in its being perceived as uncomfortably loud. This gain mechanism forms the basis for sound therapy desensitization treatment in listeners with hyperacusis.

Going back to our earplug study, I can tell you that when people wore the earplug, they generally reported tinnitus, and when they removed the earplug after 1 week, they often reported hyperacusis. The central neural processes may increase the gain because the plugged ear is deprived of input. This is revealed by a lower sound level required to elicit the acoustic reflex. This is another clear demonstration of the effect of experience on sensory processing in the adult brain.

19 Are you doing any more studies on brain plasticity?

We sure are. First, we're in the middle of a large 3-year study with adults who are fitted with one versus two hearing aids. We are particularly interested in knowing: if there is a relationship between physiological and perceptual changes, if we can predict the adults that will show a change, and if the changes have any bearing on real-life benefit.

Second, we are investigating the changes that occur in adults who lose their hearing in one ear as a result of surgery to remove an acoustic neuroma. This is quite a dramatic and sudden deprivation. Before surgery, many have hearing in both ears, but afterwards they have no hearing on the operated side. We have yet to publish this work, but we definitely see physiological changes in the brain after the surgery.

Finally, we are doing more earplug studies on normal-hearing people because we would like to investigate this change in central gain further.

20 Well, it's a fascinating area, and it's good to know that brain plasticity may be beneficial.

That's quite a bold statement and not necessarily correct. People with phantom limbs don't think brain plasticity is a good thing. And people with tinnitus, sometimes described as a phantom sensation of sounds, would likely agree. We have a considerable way to go with our research, but this work does show us that there is more to hearing than just our ears.

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