Hearing in Humans

Auditory Information comes into the brain tonotopically. That means that all the frequency information from low to high, bass to treble, is carried by nerves in an order using a row of 10,000 hair and nerve cells which, with vestibular sensory inputs makes up the cochlear nerve running from each ear into the brain. Each individual nerve cell is highly myelinated, so as to insulate and contain the electrical signal being carried. This ensures the electrical signals do not ‘bleed across’ to other nearby nerves, which would confuse the tonotopic organisation, and potentially, if enough nerve cells were additionally triggered, effectively overamplify the signal. This tonotopic organisation is also important for helping the brain organise audio spatial awareness and related responses later on.

All frequencies come into the base of the brain very close to the primary (and evolutionarily the most ancient) arousal centre, located in the reticular activating system. They are thought to establish a threshold, effectively a summed, running average of all background noise levels.

Any new noises that suddenly or unexpectedly exceed this threshold, might be the result of an environmental threat, and therefore can elicit and a strong and automatic arousal response. This is one mechanism by which a small noise on a silent night can scare us, yet a much louder noise can be ignored in a noisy room. The threshold can move up and down! Another protective mechanism involves two muscles in the inner ear. These are the tiniest striated muscles in the human body. They are called the tensor timpani and the stapedius and are attached to the malleus bone and the stapes bones in the inner ear respectively. In humans if the ear drum experiences a very sudden movement, e.g. a loud noise that moves the ear drum strongly and quickly enough to cause tissue damage, then these muscles activate and stiffen the bones effectively preventing signal transmission into the inner ear. This reflex also becomes active before we speak. If any of these mechanisms fail to work properly you have a potential basis for a Hyperacusis response (over sensitivity to sound).

All frequencies enter the cochlear nuclei (one for each side of the head/brain). As described above they do so tonotopically. From here they are split into three major brain pathways, each of which is still tonotopic.

- FIRSTLY to the reticular activating system for protective arousal responses.

- SECONDLY to the inferior and then superior colliculi. These two structures are responsible for creating an audio spatial sense which can then accurately drive the muscles of the head neck and eyes towards sound stimuli. The inferior colliculus handles the audio spatial field and the superior colliculus the visuospatial field. They therefore form an important part of the attentional system. Persistently poor auditory input can result in this area not calibrating properly with the result that clients experience rapid disorientation under certain auditory conditions, e.g. noise, or busy audio spatial environments e.g. a crowded room. This sometimes causes as a form of auditory defensiveness, where an aversion to busier environments results.

- ❖ THIRDLY to the auditory cortex, via the medial geniculate nucleus (in the thalamus) for the purposes of conscious appreciation and understanding the meaning of the auditory environment, including language. The medial geniculate nucleus processes and sorts the soundscape in a number of different ways, comparing and possibly sorting all sound frequencies using their speed, inertial and volume characteristics. It is possible that it gathers the frequencies relevant to each actual sound in our environment. This information is passed on to the auditory cortex. It is here that conscious meaning is ascribed to all and any relevant patterns. This forms an important part of childhood learning. Once again poor auditory information (sensory feed) due to any problems earlier the pathway will cause faulty learning.

  Importantly this can also occur if arousal responses earlier in the sensory pathway are not accurately modulated to actual environmental events leading either to poor attention, over excited attention or traumatic learning responses. In the latter, meaning and related arousal states are simply not memorised together (or later recalled) in a useful way.

FREQUENCIES AND THEIR USES

Low frequencies are considered to be organising (they are used by the Cochlear to tune it to correct pitch) and set the basis for correctly perceiving and placing higher pitched frequencies. This is a combined biomechanical and neurological process with the biomechanical process tensioning the basilar membrane in line with neurological signals from the 10,000 hair cells. It's a bit like tuning a kettle drum in the inner ear!

There is evidence to suggest that mid and high frequencies are split higher up in the brain, either in the medial geniculate region of thalamus or later in the auditory cortex, with middle frequencies being sent to the parts of the cortex that process speech sounds for word meaning, and the high frequencies being sent to the emotional centres of the brain, where language can be filtered for it's emotional meaning. This may provide an explanation for the effectiveness of voice modulation techniques, where the use of mid and low tones, with rhythmical cadence and pausing is used to help convey meanings more effectively, especially for people with auditory processing difficulties. It may also explain why higher frequencies in the human voice convey and communicate excitement. In autism this can often result in an over excitatory response. In effect children hear the emotion and becoming over aroused struggle to process the meaning the meaning of what is being said.

NB Expand on the pinnae, the energy vs frequency (physics) of different sound waves and how the ear uses this to achieve additional info on spatial placement of sounds.

THE IMPORTANCE OF TIMING

Throughout the auditory pathway structures are filtering the tonotpic soundscape for important information. It is filtering out and responding to arousal events by use of thresholds, establish an audiospatial sense of the environment needed for driving the attentional responses of the eyes, head, neck and shoulders, and lastly sending on to the cortex where meanings can be established and evaluated.

This needs to be achieved in real time. Therefore, any delay to the signal will result in auditory processing difficulties.

In practice, whilst it's reasonable that delays in the processing of any sense will cause the central nervous system difficulties, the auditory system is particularly sensitive to these difficulties, and slowed processing can throw the entire central nervous system into disarray.

This is with good reason! Long ago, when the auditory system first evolved, it was as an alert/warning system. It evolved to be able to process information extremely quickly. This is why the information is split by the cochlear nuclei as it comes into the brain and then sent separately to each higher level for attentional and meaningful processing. Sending information up through each level for processing and then passing it on to the next would be too slow, a bit like a train having to stop at each station. Instead the brain has come up with three expresses, each with their own mainlines running to arousal, attentional and thinking destinations simultaneously. If signals slow for any reasons, e.g. lack of myelination causing weak transmission, then presence of threats or the meaningfulness of language cannot be understood in real time.

Furthermore delays on one or other side of the brain can cause auditory information to arrive at the left and right sides of the cortex at different times. This can lead to misplacement of stimuli, duplication of sounds and/or threat meanings, and cause serious difficulties in directing attention correctly with in the environment. For these reasons, in the auditory system more than most, timing is everything.

It is possible that some autistic children develop echolalia in an attempt to cope with this state of affairs, in effect snatching and trying preserve at least some auditory information from the auditory onslaught. The problem then arises as this becomes an ingrained, and therefore difficult to counter, process.