NEUROANATOMY

How does behavioral training influence sound frequency discrimination?

With hearing loss affecting 35 million Americans, ferrets have been used to study frequency discrimination in the auditory cortex in aims to improve current engineered sensory signaling systems.

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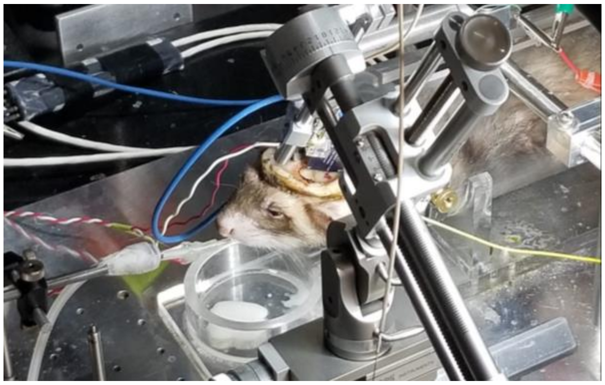
In a paper recently published in Nature Communications, Sophie Bagur et al., investigate the effects of behavioral training on the auditory cortex of ferrets.[1] Their goal was to understand how and where in the brain sensory representation transform into abstract percepts. Originally, primary sensory areas played a role in extracting and encoding high-level stimulus attributes, but recent studies in awake animals have challenged this perception and shown that information represented in primary areas depends on the behavioral state of the animals. This study supports the claims of previous studies challenging this perception while also focusing on the correlation between encoding from a sensory stimulus and behavioral driven response in the primary auditory cortex.



Exposed brain area where electrodes are inserted. *This figure shows the ferret in a soundproof booth with the sprout directly under his nose to sense the water to lick at the appropriate frequency. It also shows the implanted headpost on the ferret as well as electrode insertion into the exposed brain area.*

To gain a better understanding of the purpose of this research, let's understand the big picture a little better. Sensorineural hearing loss accounts for about 90% of reported hearing loss[2] affecting 35 million Americans.[3] The root cause is from inner ear hair cell damage as well as from nerve damage which disrupts the transmission of sound from the inner ear to the brain.[4] From the inner ear, sound is transmitted to the auditory cortex which is located in the temporal lobe. More specifically, the auditory cortex is located on the superior temporal gyrus in the temporal lobe[5] and is essential for hearing and understanding speech.[6] The auditory cortex is composed of two main regions, primary auditory cortex and the secondary auditory cortex. The primary auditory cortex (AI) is composed of neurons which function to decode the organized representation of a sound stimulus as well as differentiate frequencies into identifiable sound.[7,8] The secondary auditory cortex (AII) is essential for sound detection and localization as well as auditory memory[7,8] and language comprehension.5 Impairment of the auditory cortex to discriminate sounds is often an effect of hearing loss since frequency discrimination is important for speech and complex sound recognition. This study is using behavioral training on ferrets to further understand the importance of processing temporal sequences of sound in the auditory cortex.[1,5,9] Without the auditory cortex, ferrets lose the ability to discriminate between two complex sounds which have similar frequency components that differ in temporal sequence.[5]

During behavioral training, adult female ferrets were trained using aversive conditioning which is the use of something unpleasant to stop an unwanted behavior (via positive reinforcement) to discriminate between high tone and low tone sound frequencies. These ferrets were trained to lick water from a spout as shown in the figure below, during the presentation of a class of reference stimuli and to stop licking after the presentation of a different class of target stimuli to avoid a mild shock. During each session, the target sound frequency changed as to require the ferrets to continue to learn a new reward association. Once the animal learned the task, neuronal activity in A1 was recorded in response to the sound stimulus and the behavioral state of the ferrets as implied in the figure below. Prior to behavioral training, the ferrets were implanted with a headpost to expose the brain of the ferrets and allow the researchers to use electrodes to record neuronal activity as explicitly shown in the ferret in the figure below. The data was then analyzed and used to guide their objective which was to further understand the correlation between encoding from a sensory stimulus and behavioral driven response in the primary auditory cortex.

During analysis, they observed increased spontaneous activity in the A1 during task-engaged conditions but did not observe a significant difference between firing patterns between high vs. low sound frequencies. This research shows that the animals were actually able to learn the task and differentiate different tone frequencies which was shown in the lick rate. They learned to only lick the sprout at specific tone frequencies and avoid it during target sound frequencies. In addition, encoding of information strongly changed in between trials when the sound shifted from a random sound stimulus to the target sound frequency. This showed a comparison of the sound decoders in the brain between the duration that the sound was played, and the ferret was licking water vs. during the target sound stimulus when the ferret stopped licking to avoid getting shocked. The primary auditory cortex therefore appeared to strongly represent information about the stimulus class.

In comparison to other studies, this research group conducted their research on ferrets instead of rodents, cats, owl monkeys, etc., for instance, due to ferret's rapid ability to learn new tasks.[10,11,12,13] Ferrets are considered smart and have a relatively similar hearing range frequency to humans, which in humans is 20 Hz to 20 kHz. With age, most people lose the ability to detect high frequency sounds while maintaining the ability to hear low frequency sounds for a longer time. A common solution has been hearing aids while those who are hearing impaired or deaf tend to use cochlear implants to detect sound. Hearing aids only amplify sounds while cochlear implants send sound signals to the brain.[15] Cochlear implants are small complex electronic devices that provide people with a sense of sounds by replacing the function of the damaged parts of the inner ear.[15] The implant consists of a small portion that is surgically placed in the inner ear and an external portion that sits behind the ear.[15] Bilateral implantations have been introduced within the last decade with hopes of improving both speech perception in background noise and sound localization.[14] There is evidence suggesting that binaural perception is possible with two implants, research results in humans are variable therefore ferrets have been used to explore potential contributing factors to these variable, inconsistent outcomes.[14] The idea of using ferrets as an animal model has opened broad possibilities of using them to study potential protective effects of bilateral cochlear implantation on the developing central auditory pathway and develop novel neuroprosthetic therapies for use in humans.[14] As shown not only in this study but additional studies as well, behavioral training enhances temporal processing parameters. This research aids in understanding frequency resolution in A1 and can be used to improve current engineered sensory systems for signaling processes.

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