“Improving Human Performance: 
Humans and the Sonar Implant”

SAMPLE

Engineering Sciences 5

Paper Assignment #1
“Introduction”

At this very moment, millions of 16 year olds across the nation are learning about the hazards of driving and the infamous “blind spot.” According to the Department of Transportation, 35% of auto-related truck fatalities occur in the truck’s blind spot.¹ Imagine if humans had the same echolocation abilities as a bat. We could keep our visual focus on the cars in front of us while still being aware of the location of cars behind us and even everything in our blind spots. Clearly, the number of driving related injuries and deaths would drastically decrease if humans could use echolocation. Human hearing is already greatly limited to the frequency range of 20 Hz to 20,000 Hz while bats can hear in the range of 20 kHz to 200 kHz.² In addition, bats and other animals use echolocation in which they produce a sound and analyze its echoes to determine physical position.³ If humans had an enhanced frequency range and the ability to use echolocation, we would be better able to multitask and keep up with our busy lives without endangering the lives of others on the road.

“Anatomy and Physiology Research”

The human ear consists of three sections: the outer ear, middle ear, and inner ear. The outer ear includes the pinna and functions to help channel sound waves into the ear canal and to determine the location of sounds by creating an interaural time difference. The middle ear consists of the ear canal and tympanic membrane or ear drum which vibrates according to the frequency. The inner ear includes the oval window, the round window, the cochlea, and the three ossicles: incus, stapes, and malleus. The cochlea transduces all sound waves into neural impulses which are then transported to the auditory nerve and to the thalamus and then to the primary auditory cortex. All sensory information except for olfactory information goes to the thalamus to be relayed and processed. The ossicles also perform a very crucial function of amplification and relieving pressure. When sound waves are transduced from air to the fluid inside an ear, much of the energy is lost and the original sound is greatly distorted. Thus, the ossicles amplify the sound to make up for the loss. The cochlea is the single most important

structure because it contains the organ of corti where sound waves are transduced into electrical signals. The organ of corti includes both inner and outer hair cells, which also act as amplifiers.4

Despite this complex, sensitive system, the human auditory system has many limitations to possible higher performance. The major issue with the auditory system is deafness or failure to hear. There are two main types of deafness: conduction and sensorineural. Conduction deafness occurs when sound waves are not properly transmitted through the outer or middle ear and can result from ear canal obstruction or puncture of the ear drum. Conduction deafness is less severe than sensorineural deafness and is not always permanent. Sensorineural deafness occurs when the inner ear or auditory nerve is damaged and is permanent. For example, if someone is born with only a partially formed cochlea, they will experience sensorineural deafness.5 An increasing number of cases of developed sensorineural deafness have been observed recently. Many researchers have speculated that the increase use of MP3 players could be the culprit. Science Direct Journal recently published an article emphasizing the importance for young adults to limit the maximum volume of their MP3 players or iPods to prevent the most common form of sensorineural deafness, Noise Induced Hearing Loss.6 This loud or sustained noise over stimulates the sensitive hair cells permanently killing them. Clearly, the forms of deafness illustrate that many of the ear’s structures such as the tympanic membrane and hair cells are prone to injury and can result in serious consequences. The sensitivity and fragility of these crucial structures is a major obstacle in the effort to expand our audible frequency range.

Many animals, such as owls, have amazing sound localization and can instantly tell exactly where a noise originated. Humans use two cues to determine where a sound is coming from: interaural time differences and interaural frequency differences. Because of the shape of the pinna, a sound coming from behind the observer will have a different distortion of the sound waves than a sound coming from in front of the observer. The brain realizes this difference and analyzes the distortion of the sound waves to make an assessment of the general location. In addition, if a sound is coming from an observer’s right hand side, it will take a longer time for the sound waves to reach the left ear as compared to the time to reach the right ear. The brain also analyzes this information to make a localization decision. However, these two cues are only

5 Blake, Perception.
effective for frequencies in either the high or low spectrum. Sound waves in the middle range of frequencies are much more difficult for humans to localize.\textsuperscript{7} Many animals overcome this limitation by having larger ears or ears that are able to move towards the sound. This current limitation of performance is a significant problem when discussing expanding human’s range of audible frequencies because it is important to not only be able to hear a sound but to also be able to localize it.

In addition to the above limitations of a limited frequency range, poor sound localization cues, and fragile ear structures, the auditory system has built in benefits that can limit our potentional for increased hearing abilities. For example, to protect our sensitive ear drum from loud noises of an extremely high frequency that will disrupt the pressure and burst the ear drum causing deafness, small bones in the middle ear clamp down and prevent the ear drum from vibrating when a sound is deemed too loud. This system also prevents humans from cognitively hearing sounds inside our bodies, such as our heart beat, blood flow, or eyes blinking.\textsuperscript{8} Since the goal is to augment humans hearing abilities, this so called beneficial mechanism could prove difficult to overcome.

“Analysis of Alternatives Presented in Animal Models”

Several animal species have overcome the human limitations of a small audible frequency range, poor sound localization, and physically vulnerable structures. In addition, other animals have augmented their hearing abilities by employing entirely different systems, such as radar and echolocation.

Bats have a clearly superior auditory system to all humans. Bats have overcome our limited frequency range and poor sound localization cues by using radar and echolocation to augment their hearing capabilities. Mouse-tailed bats (\textit{Rhinopoma hardwickei}) rely very heavily on their auditory sense for survival. Their prey consists mainly of flying insects and they use echolocation to identify exactly where they are. These bats emit auditory signals at paces ranging from 20-100 signals per second and usually lasting 2-10 milliseconds depending on the stage of feeding. For example, if a bat is in the searching phase, it will emit a sonar sound 6-10 ms in duration 10-20 times per second. These multiple-harmonic, short duration sonar sounds can be of a constant frequency or frequency modulated ranging from 18-80 kHz. Most of these


\textsuperscript{8} Blake, \textit{Perception}. 
sonar sounds are inaudible to humans whose maximum audible frequency is approximately
20,000 Hz or 20 kHz. These bats then analyze the returning echoes in terms of their time to
return and the quality of the echo sound to determine the location of their insect prey.\textsuperscript{9} Clearly,
since the bat has an augmented frequency range that does not puncture their ear drum and has
superior sound localization skills, its auditory system is an appropriate model for researchers
aiming at augmenting human hearing.

In addition, dolphins use a similar system of sonar echolocation to enhance both their
audible frequency range and their sound localization abilities. Since the mid 1950s, scientists
from many different disciplines have devoted their lives to studying the auditory systems of
dolphins which have an incredibly large audible frequency range of 100 Hz- 150 kHz. Like bats,
dolphins use sonar echolocation to augment the information from their auditory systems. Their
lower jaw is the primary site for receiving these sonar signals rather than the ear canal and
auditory nerve.\textsuperscript{10} This represents one way to overcome the human limitation of having an ear
drum that bursts under high frequency noises.

In addition, to the two above examples of sonar use in animals, scientists funded by the
National Institute of Deafness and other Communication Disorders (NIDCD) discovered that the
amolops tormotus or the concave eared torrent frog has an extra ear canal which allows it to hear
higher frequency sounds than normal. This extra capability also allows it to communicate
through emitting and receiving ultrasounds. As mentioned, this ability has been detected in
mammals, but the concave eared torrent frog is the first non-mammalian animal species to have
this capability. Researcher James F. Battey, M.D. Ph.D., director of the NIDCD, emphasized the
importance of this animal model by stating, “In the study of communication and communication
disorders, researchers can gain a great deal of insight by looking at the natural world. The more
we can learn about the extraordinary mechanisms that Amolops and other animals have
developed to hear and communicate with one another, the more fully we can understand the
hearing process in humans, and the more inspired we can be in developing new treatments for

\textsuperscript{9} Simmons, J. et al. (1984). Echolocation and hearing in the mouse-tailed bat, \textit{Rhinopoma hardwickei}:
acoustic evolution of echolocation in bats. \textit{Journal of Comparative Physiology A: Neuroethology, Sensory, Neural,
and Behavioral Physiology}. 154.

\textsuperscript{10} Brill, R. et al. (2001). Assessment of dolphin (\textit{Tursiops truncatus}) auditory sensitivity
hearing loss.” According to the study, several structural aspects differ in this frog compared to humans that allow them to hear these high pitched ultrasounds. For example, the frogs’ ear drum is much thinner than humans so that it can properly vibrate at high frequencies without bursting. Also, the inner ear bones are much more lightweight than the malleus, incus, and stapes in humans. The extra ear canal protects the ear drum and helps it remain functional at these high frequencies.

These animal models often inspire scientists to believe that it is possible to augment human hearing and allow us to communicate through sonar, but even more inspiring are the few cases where humans have exceeded their own limitations. For example, Ben Underwood of California lost his sense of vision at a very young age when the brain is still plastic and capable of rewiring. He soon began “clicking” and learned to use echolocation in order to navigate the world. Ben makes a clicking noise with his tongue and then listens to how the echoes are returned in order to create visual images of his surrounding stimuli. He can even play basketball by analyzing the difference between the bouncing of the echoes on the backboard versus the sound waves that bounce of the hoop. Most humans can not use echolocation like Ben because their brain is not adapted for such a function. Since Ben lost both his eyes from cancer at a young age, his visual cortex had not fully developed yet. Therefore, when he started “clicking,” his visual cortex, which was previously receiving no sensory input, remapped to process input from the returning echoes.

“Analysis of Technological Alternatives”

Scientists are currently working on several technologies to allow for humans to communicate with sonar and to use echolocation, but have made the most advancements on overcoming the lack of durability of physical structures. For example, the cochlear implant has helped many people with sensorineual deafness regain some hearing. As mentioned, sensorineual deafness involves damage to the inner ear, such as the hair cells in the organ of corti.

---


The cochlear implant bypasses the damaged inner ear and transduces sounds directly onto the auditory cortex. It consists of an external portion and an internal portion. An entire cochlea implant includes a microphone, a speech processor to arrange sounds picked up from the microphone, a transmitter and receiver, that converts signals from the processor into electrical signals, and an electrode which sends impulses to the auditory nerve. (Please see attached figure.) The auditory nerve then sends the information to the thalamus and then to the auditory cortex. This implant has improved many lives by bypassing the human’s own transduction system with an electronic analogue. However, today’s cochlear implant is still very primitive and does not transduce sounds the same as someone’s natural cochlea would; rather, it provides a basic representation of the auditory stimuli in the surrounding environment.\(^\text{14}\) Nonetheless, one recent study showed that deaf individuals who recently underwent surgery for the cochlear implant showed remapping of the brain’s auditory cortex to form a tonetopic map remarkably similar to the auditory cortex of a normal hearing person.\(^\text{15}\) This illustrates the great plasticity of the human brain and the promise it holds for the future.

The cochlear implant is the most advanced technology currently available to augment or replace someone’s natural hearing or lack thereof. But, for years people with gradual hearing loss have taken advantage of the benefits of hearing aids which are electronic devices that amplify current environmental noises. The typical hearing aid consists of a microphone which transduces sounds to electrical signals, an amplifier, and a speaker. A hearing aid gives a person with sensorineural deafness no relief from their unending silence because the sounds amplified by the microphone still need to pass through the cochlea which is usually damaged in sensorineural deafness. Nonetheless, people suffering from loss of hearing have greatly benefitted from this simple device.\(^\text{16}\)

The next frontier of treatment for those with hearing problems lies with the genetics technology currently being developed. A few months ago, researchers at the University of Virginia Health System led by Dr. Jeffry Holt isolated the gene responsible for genetically acquired hearing loss, KCNQ4. Dr. Holt’s team then genetically engineered the correct version


and developed a new gene therapy delivery system which transferred the gene into human inner hair cells. Dr. Holt had this to say of this great advancement, “Our results show that gene therapy reagents are effective in human inner ear tissue. Taken together with the results from another group of scientists who showed that similar gene therapy compounds can produce new hair cells and restore hearing function in guinea pigs suggest that the future of gene therapy in the human inner ear is sound.”

This promising genetic technology along with the cochlear implant is the newest treatments available today.

“Recommendation for Improved Design”

Humans could benefit greatly from an improved design that allows everyone to hear from a frequency level of 20 Hz to 200 kHz and localize sounds using echolocation and sonar. There are several steps necessary to implement this new design into society. First, scientists would need to overcome many of the limitations of human’s current performance. An ideal system would be a combination of the cochlear implant technology with that of genetics basing the final design on the several animal models. Before changing the human genome to forever include an expanded audible frequency range and sonar capabilities, scientists would develop a Sonar Implant that would resemble an extra ear and would be surgically implanted to transduce directly onto the brain cortex. This implant would be similar to the cochlear implant and would include a microphone specially designed to pick up high frequency sonar sounds, an ultrasound processor to transmit extremely high frequencies and echoes, a transmitter, receiver, and finally an electrode to pass the information directly into the association cortex. However, instead of an electronic stimulator, it would more closely resemble the structures of a human ear, only more durable. For example, it would have lighter weight ossicle bones and a thinner tympanic membrane, just like some frogs with ultrasound communication abilities. In addition, there would be another device that created ultrasound noises with varying duration and rate, just like those sounds created by bats and dolphins. Thus, humans would not have to constantly alter their “clicking” because the machine in their brain would automatically create sonar sounds. Then when the echoes bounced back, the processor and transmitter would convert them into electrical signals that instead of being directly transmitted onto the auditory nerve, the information would be transmitted onto the primary sensory association cortex. Thus, the

---

Echolocation information would be automatically included in combining all sensory information and would not be treated as auditory information but as information from a sixth sense. This development of a sixth sense has many great advantages because if sonar information was incorporated into the auditory cortex, it would become mixed up with basic auditory information and has the potential to be distracting. Humans would have to be constantly attending and focusing on the echo information in addition to listening to human speech and other basic information. By bypassing the auditory cortex and going directly to the primary sensory association cortex in the brain, it eliminates this possible disadvantage of extra information becoming more of a distraction than a benefit. While this Sonar Implant was being adopted into mainstream society, geneticists would concurrently be working on isolating the genes responsible for brain remapping, our frequency range, and the durability of our ear structures. Eventually, they would isolate these genes and be able to technologically alter our genome so that we had an extra ear canal, thinner ear drum, and lighter weight ossicles. Thus, all of the functions of the Sonar Implant would be passed on to our ancestors and would forever become part of our human functions.

This Sonar Implant offers infinite advantages to the human race. As mentioned earlier, we would have extra information from a sixth sense and could perfect several tasks that are limited by our lack of precision as humans. We would know exactly where objects were located in 3-D space and could pinpoint where a fruit fly was in a large room with our eyes closed, just like the bats. This holds tremendous promise in preventing car accidents due to lack of visual information. Many people insist on speaking on the cell phone, changing the CD, or putting on make-up while driving. With this new sixth sense and the Sonar Implant, people could read a book while driving safely because their Sonar Implant would pick up on the location of roadblocks and possible hazards. Increased driving safety is only the beginning. During surgery, surgeons would be able to locate organs and small blood vessels just by analyzing how much of the sonar passes through the organs. For example, less of an echo would be returned if bone lay beneath the skin than if fluid lay beneath the skin. This sixth sense has great potential to be the largest advancement in human performance in this century.

However, despite all of these advantages and benefits, some disadvantages and obstacles lie ahead. For example, humans only have a limited attention span and despite the extra incoming sensory information, can not process all of the information. Thus, in order for the
Sonar Implant to have a large impact on society, geneticists would have to discover a way to also expand the human’s attention span.

In addition to the echolocation abilities of the Sonar Implant, it would also have the capability of transmitting information about one’s internal environment directly to the brain. For example, part of the Sonar Implant will have an extremely high sensitivity level and be specially tuned to monitor all internal noises, such as heart rate and bile secretion. Auditory information from our inner organs would constantly be transmitted to the Sonar Implant and into our brain, but we would only attend to this information and be aware of its existence if a problem arose. For example, every time our heart beats, that sound would be transmitted by the Sonar Implant and sent to our cortex, but cognitively, we would be unaware of it, just like we are now. But as soon as our processing cortex in the brain recognized an irregularity or absence of the heart sounds, it would be brought to our attention. Thus, humans could prevent an infinite number of diseases. For example, our brain would be monitoring the auditory signals of cell division and would notice immediately when cells began dividing irregularly. Thus, doctors would know the moment the cancer started and treatment would be much more successful.

Clearly, enhancement of our auditory system through the Sonar Implant holds great promise for improving human performance in an unlimited number of fields.
Bibliography


