

Human Echolocation: Seeing the World Through Sound

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Human echolocation is the ability of humans to detect objects in their environment by sensing echoes from those objects, by actively creating sounds - for example, by tapping their canes, lightly stomping their foot, snapping their fingers, or making clicking noises with their mouths - people trained to orient by echolocation can interpret the sound waves reflected by nearby objects, accurately identifying their location and size. This ability is used by some blind people for acoustic wayfinding, or navigating within their environment using auditory rather than visual cues. It is similar in principle to active sonar and to animal echolocation, which is employed by bats, dolphins and toothed whales to find prey.

Background

The term "echolocation" was coined by zoologist Donald Griffin in 1944; however, reports of blind humans being able to locate silent objects date back to 1749. Human echolocation has been known and formally studied since at least the 1950s. In earlier times, human echolocation was sometimes described as "facial vision" or "obstacle sense," as it was believed that the proximity of nearby objects caused pressure changes on the skin. Only in the 1940s did a series of experiments performed in the Cornell Psychological Laboratory show that sound and hearing, rather than pressure changes on the skin, were the mechanisms driving this ability. The field of human and animal echolocation was surveyed in book form as early as 1959. See also White, et al. (1970)

Many blind individuals passively use natural environmental echoes to sense details about their environment; however, others actively produce mouth clicks and are able to gauge information about their environment using the echoes from those clicks. Both passive and active echolocation help blind individuals learn about their environments.

Because sighted individuals learn about their environments using vision, they often do not readily perceive echoes from nearby objects. This is due to an echo suppression phenomenon brought on by the precedence effect. However, with training, sighted individuals with normal hearing can learn to avoid obstacles using only sound, showing that echolocation is a general human ability.

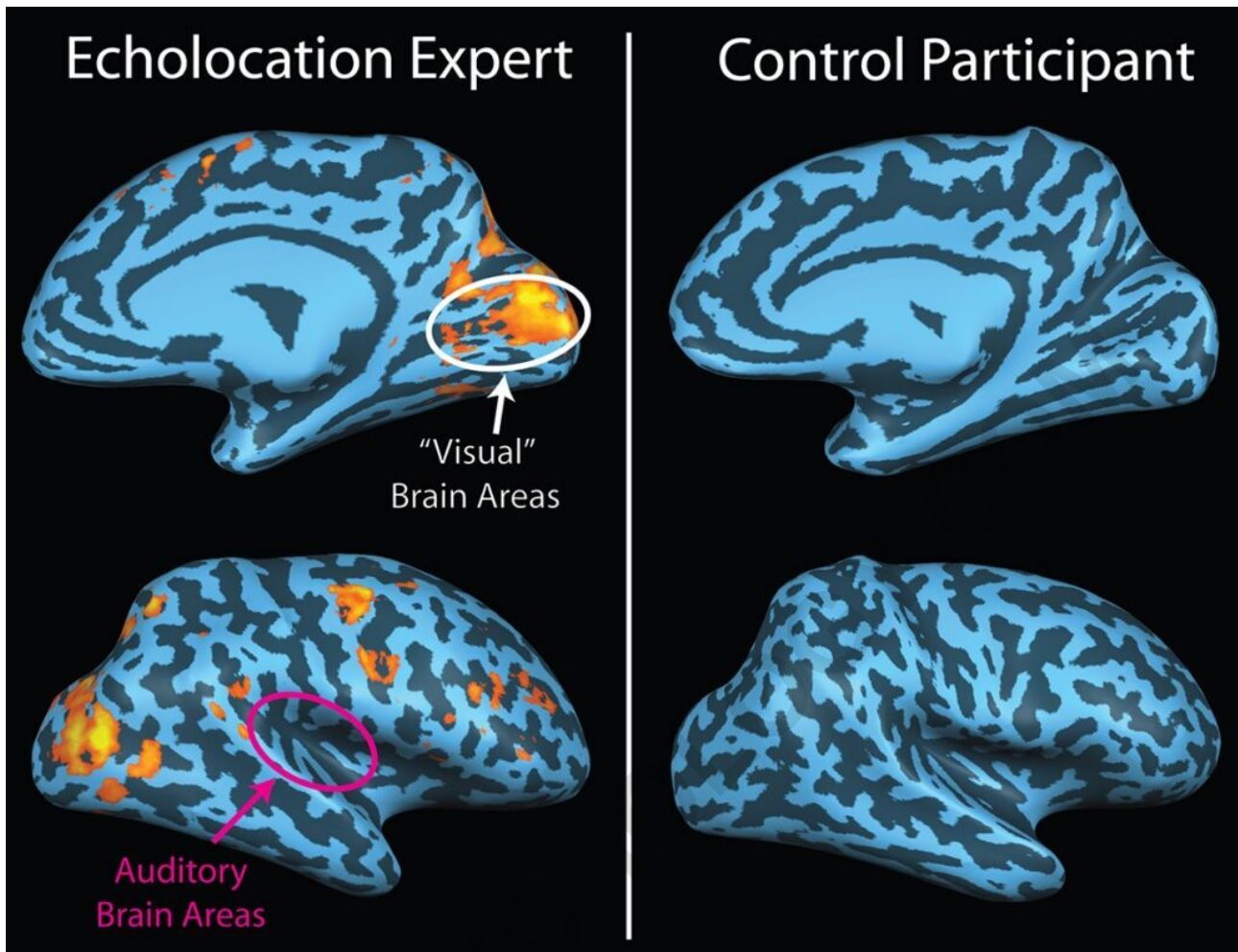
Mechanics

Vision and hearing are closely related in that they can process reflected waves of energy. Vision processes light waves as they travel from their source, bounce off surfaces throughout the environment and enter the eyes. Similarly, the auditory system processes sound waves as they travel from their source, bounce off surfaces and enter the ears. Both systems can extract a great deal of information about the environment by interpreting the complex patterns of reflected energy that they receive. In the case of sound, these waves of reflected energy are called "echoes".

Echoes and other sounds can convey spatial information that is comparable in many respects to that conveyed by light. With echoes, a blind traveler can perceive very complex, detailed, and specific information from distances far beyond the reach of the longest cane or arm. Echoes make information available about the nature and arrangement of objects and environmental features such as overhangs, walls, doorways and recesses, poles, ascending curbs and steps, planter boxes, pedestrians, fire hydrants, parked or moving vehicles, trees and other foliage, and much more. Echoes can give detailed information about location (where objects are), dimension (how big they are and their general shape), and density (how solid they are). Location is generally broken down into distance from the observer and direction (left/right, front/back, high/low). Dimension refers to the object's height (tall or short) and breadth (wide or narrow).

By understanding the interrelationships of these qualities, much can be perceived about the nature of an object or multiple objects. For example, an object that is tall and narrow may be recognized quickly as a pole. An object that is tall and narrow near the bottom while broad near the top would be a tree. Something that is tall and very broad registers as a wall or building. Something that is broad and tall in the middle, while being shorter at either end may be identified as a parked car. An object that is low and broad may be a planter, retaining wall, or curb. And finally, something that starts out close and very low but recedes into the distance as it gets higher is a set of steps. Density refers to the solidity of the object (solid/sparse, hard/soft). Awareness of density adds richness and complexity to one's available information. For instance, an object that is low and solid may be recognized as a table, while something low and sparse sounds like a bush; but an object that is tall and broad and very sparse is probably a fence.

Neural substrates of echolocation in the blind



Echo-related activity in the brain of an early-blind echolocator is shown on the left. There is no activity evident in the brain of a sighted person (shown on the right) listening to the same echoes

Some blind people are skilled at echolocating silent objects simply by producing mouth clicks and listening to the returning echoes, for example Ben Underwood. Although few studies have been performed on the neural basis of human echolocation, those studies report activation of primary visual cortex during echolocation in blind expert echolocators. The driving mechanism of this brain region remapping phenomenon is known as neuroplasticity.

In a 2014 study by Thaler and colleagues, the researchers first made recordings of the clicks and their very faint echoes using tiny microphones placed in the ears of the blind echolocators as they stood outside and tried to identify different objects such as a car, a flag pole, and a tree. The researchers then played the recorded sounds back to the echolocators while their brain activity was being measured using functional magnetic resonance imaging. Remarkably, when the echolocation recordings were played back to the blind experts, not only did they perceive the objects based on the echoes, but they also showed activity in those areas of their brain that

normally process visual information in sighted people, primarily primary visual cortex or V1. This result is surprising, as visual areas, as their names suggest, are only active during visual tasks. Most interestingly, the brain areas that process auditory information were no more activated by sound recordings of outdoor scenes containing echoes than they were by sound recordings of outdoor scenes with the echoes removed. Importantly, when the same experiment was carried out with sighted people who did not echolocate, these individuals could not perceive the objects and there was no echo-related activity anywhere in the brain. This suggests that the cortex of blind echolocators is plastic and reorganizes such that primary visual cortex, rather than any auditory area, becomes involved in the computation of echolocation tasks.

Despite this evidence, the extent to which activation in the visual cortex in blind echolocators contributes to echolocation abilities is unclear. As previously mentioned, sighted individuals have the ability to echolocate; however, they do not show comparable activation in visual cortex. This would suggest that sighted individuals use areas beyond visual cortex for echolocation.

Notable individuals who employ echolocation

Daniel Kish

Echolocation has been further developed by Daniel Kish, who works with the blind, leading blind teenagers hiking and mountain-biking through the wilderness and teaching them how to navigate new locations safely, with a technique that he calls "FlashSonar", through the non-profit organization World Access for the Blind. Kish had his eyes removed at the age of 13 months due to retinal cancer. He learned to make palatal clicks with his tongue when he was still a child--and now trains other blind people in the use of echolocation and in what he calls "Perceptual Mobility". Though at first resistant to using a cane for mobility, seeing it as a "handicapped" device, and considering himself "not handicapped at all", Kish developed a technique using his white cane combined with echolocation to further expand his mobility.

Kish reports that "The sense of imagery is very rich for an experienced user. One can get a sense of beauty or starkness or whatever - from sound as well as echo". He is able to distinguish a metal fence from a wooden one by the information returned by the echoes on the arrangement of the fence structures; in extremely quiet conditions, he can also hear the warmer and duller quality of the echoes from wood compared to metal.

Ben Underwood

Ben Underwood

Diagnosed with retinal cancer at the age of two, American Ben Underwood had his eyes removed at the age of three.

He taught himself echolocation at the age of five. He was able to detect the location of objects by making frequent clicking noises with his tongue. This case was explained in 20/20: Medical Mysteries. He used it to accomplish such feats as running, playing basketball, riding a bicycle, rollerblading, playing football, and skateboarding. Underwood's childhood eye doctor claimed that Underwood was one of the most proficient human echolocators.

Underwood died on January 19, 2009 at the age of 16, from the same cancer that took his vision.

Tom De Witte

Tom De Witte was born in 1979 in Belgium with bilateral congenital glaucoma. It had seemed that De Witte would become a successful flautist until he had to give up playing music in 2005. De Witte has been completely blind since 2009 due to additional problems with his eyes. He was taught echolocation by Daniel Kish and was given the nickname "Batman from Belgium" by the press.

Dr. Lawrence Scadden

Dr. Scadden has written of his experiences with blindness. He was not born blind, but lost his sight due to illness. As a child, he learned to use echolocation well enough to ride a bicycle in traffic.

(His parents thought that he still had some sight remaining.) He later participated in experiments in facial vision (White, et al. 1970). About 1998, he visited the Auditory Neuroethology Laboratory at the University of Maryland and was interviewed about his experience with facial vision. The researchers in the lab study bat echolocation and were aware of the Wiederiorientierung phenomenon described by Griffin (1959), where bats, despite continuing to emit echolocation calls, use path integration in familiar acoustic space. Dr. Scadden indicated that he found echolocation effortful, and would not use it to navigate in familiar areas unless he were alert for obstacles, thus providing insight into the bat behavior.

The Regional Alliance of Science, Engineering and Mathematics for Students with Disabilities (RASEM) and the Science Education for Students With Disabilities (SESD), a Special Interest Group of the National Science Teachers Association (NSTA) have created the Lawrence A. Scadden Outstanding Teacher Award of the Year for Students With Disabilities in his honor.

Lucas Murray

Lucas Murray, from Poole, Dorset, was born blind. He is believed to be one of the first British people to learn to visualise his surroundings using echolocation, and was taught by Daniel Kish.

Kevin Warwick

The scientist Kevin Warwick experimented with feeding ultrasonic pulses into the brain (via electrical stimulation from a neural implant) as an additional sensory input. In tests he was able to accurately discern distance to objects and to detect small movements of those objects.

Juan Ruiz

Blind from birth, Juan Ruiz lives in Los Angeles, California. He appeared in the first episode of Stan Lee's Superhumans, titled "Electro Man". The episode showed him capable of riding a bicycle, avoiding parked cars and other obstacles and identifying nearby objects. He entered and exited a cave, where he determined its length and other features.

In popular media

Toph Bei Fong



An illustration of Toph's mechanoreceptor ability to feel vibrations through the ground, similar to sonar.

Toph is a fictional blind girl from the animated series Avatar: Last Airbender who uses a highly advanced form of echolocation through a technique called "earthbending" (telekinetic manipulation of elemental earth). Being born blind, she has developed hyper-sensitive mechanoreceptors and is able to feel the minute vibrations in the Earth well enough to create an accurate mental picture of her surroundings. Along with her heightened sense of smell and hearing, she uses her abilities to succeed in combat, though she's left vulnerable when her opponents are airborne. Using her extremely refined abilities, she can also sense the vibrations of a person's heart-rate and breath-rate, effectively becoming a human polygraph.

Perception

The 2017 video game Perception places the player in the role of a blind woman who must use echolocation to navigate the environment.

The Last of Us

In Naughty Dog's 2013 PlayStation 3 game, The Last of Us, infected people called "clickers" use echolocation.

Imagine

In the 2012 movie Imagine, the main character teaches echolocation to students at clinic for the visually impaired. This unconventional method spurs a controversy but helps students explore the world.

Daredevil

Matthew Murdock is a defense attorney by day, and a crime-fighting vigilante by night going by the name Daredevil, from Marvel Comics. He was involved in an accident as a child where his eyes came in contact with radioactive chemicals, effectively blinding him though it did enhance his other senses (smell, hearing and touch) to superhuman-levels. If he concentrates hard enough, he is able to hear a person's cry for help from blocks away. Like Toph Beifong, he can use his super-hearing to detect a person's heartbeat as well as minute changes of their breath-rate and tone of voice, thus also becoming a human lie-detector. Also like Toph, he uses his abilities to his advantage in combat.

Artificially stimulated echolocation for blind humans

Currently ongoing research

Project BATEYE fundamentally uses an ultrasonic sensor mounted onto a wearable pair of glasses that measures the distance to the nearest object and relays it to an Arduino board. The Arduino board then processes the measurements and then plays a tone (150-15000 Hz) for the respective distance (2 cm to 4 m) till the data from the next ultrasonic pulse (distance) comes in. This cycle is repeated almost every 5 milliseconds. The person hears sound that changes according to the distance to the nearest object. The head provides a 195-degree swivel angle and the ultrasonic sensor detects anything within a 15-degree angle. Using systematic, cognitive and computational approach of neuroscience, with the hypothesis that the usage of the occipital lobe of blind people goes into processing other sensory feedback, and using the brain as a computational unit, the machine relies on the brain processing the tone produced every 14 mS to its corresponding distance and producing a soundscape corresponding to the tones and the body navigating using the same. During experimentation, the test subject could detect obstacles as far away as 2-3 m, with horizontal or vertical movements of the head the blindfolded test subject could understand the basic shape of objects without touching them, and the basic nature of the obstacles.

Similar research could potentially revolutionize navigation abilities of blind humans.