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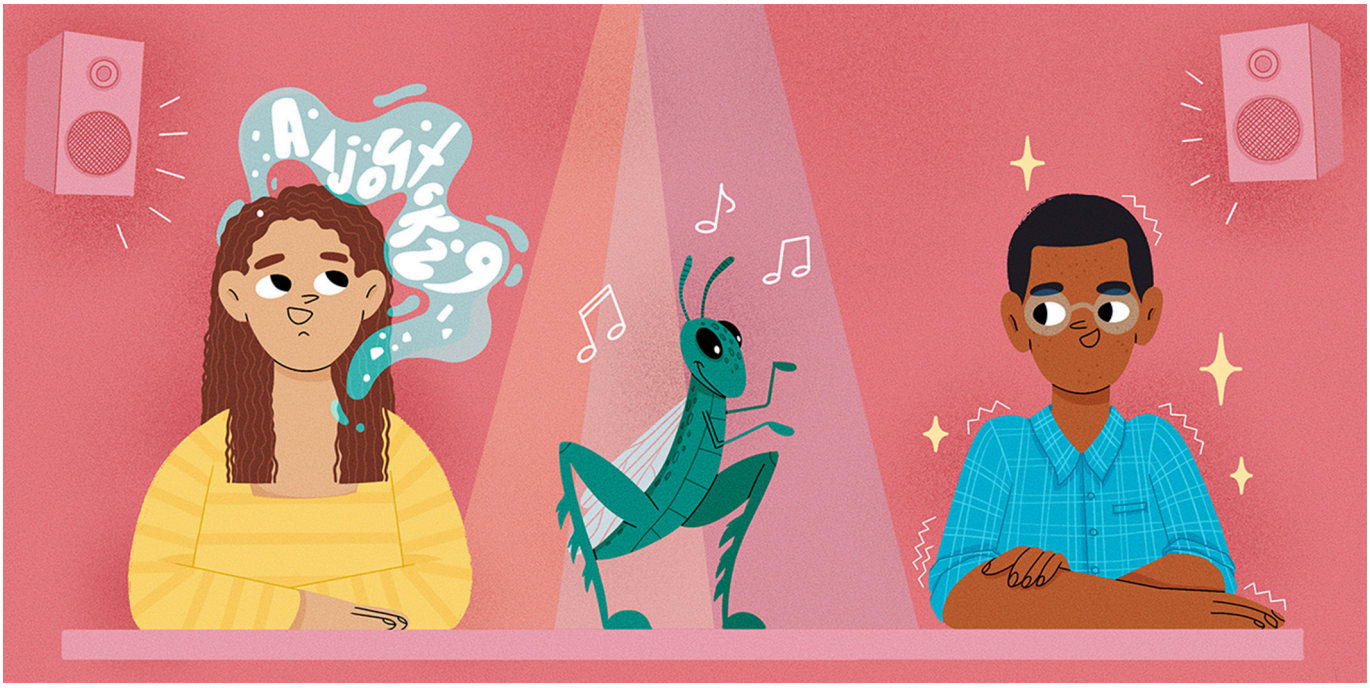

CAN WE COMBINE SENSES TO CREATE NEW "SUPER SENSES" AND ABILITIES?

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YOUNG REVIEWERS

"ORT DAFNA" MIDDLE SCHOOL, KIRYAT BIALIK

AGE: 13

Bats see with their ears, snakes see heat, horses can see almost 360° around them, and crickets have super hearing abilities through their legs. The development of these abilities took 10's of 1,000's of years of evolution. While these astonishing sensory abilities may sound like superpowers that only people in comic books have, new studies suggest that, by using technology and perceptual learning, humans too could develop some of these awe-inspiring abilities—sometimes with only a small amount of training!

WHAT DO WE KNOW ABOUT THE SENSES?

In school, you learned about the five senses: sight, hearing, taste, touch, and smell. Maybe you even learned how each sense sends a message to a specific area in the brain for processing—that there is a vision center, a hearing center, and so on. But recent research suggests that this simple division is not entirely true and definitely does not paint

the whole picture [1]. Studies reveal hidden connections between the senses, and these connections serve as gates that transmit information from one sense to another to allow the senses to be "blended" together. These gates allow researchers to "hack" the brain (only with the consent of the participants and for a positive purpose, of course) to improve and expand the classical senses.

We get a glimpse into these hidden sensory connections in people who have **synesthesia**, a conditions in which the brain mixes up the senses. Strong synesthesia, such as seeing colors when reading the letters of the alphabet or seeing shapes when listening to music, is found in a small percentage of the population. But a milder form of synesthesia is much more common, in which noises like whispering, tapping, or crinkling paper generate pleasant current or touch-like sensations. So, what can be done with these hidden connections between the senses?

SYNESTHESIA

A phenomenon in which stimulation of one sense leads to stimulation of another sense, resulting for example in seeing shapes or colors when hearing music.

HEARING THROUGH YOUR FINGERS

Have you ever listened to a song and felt the beat in your body? The ability to feel sounds is well-documented in nature (Figures 1A,B), and some creatures are even known to hear without having ears! This ability has its origins in the nature of sound itself. Sounds are basically waves that travel through the air and enter the ears. The waves hit the eardrums, which jiggle and send the vibrations to a structure in the middle ear, composed of three tiny bones. These bones send the vibrations to the inner ear, which is the point where the mechanical vibrations of sound become an electrical signal, which is sent to the brain through the nerves. The inner ear is filled with fluid and lined with microscopic hairs. When sound wave vibrations enter the inner ear and create waves in this fluid, the hair cells move, which generates an electrical signal. The signal is then sent to the brain's **auditory cortex** *via* the auditory nerve.

AUDITORY CORTEX

An area of the brain where auditory information is usually believed to be processed.

Vibration is the key to hearing. Our lab constructed a device that can convert speech and other sounds to vibrations that are felt on the fingers (Figure 1C). We discovered that these vibrations to the fingers enhanced people's ability to hear the speech or sound, providing an immediate increase in hearing in noisy environments! In other words, their hearing capabilities increased significantly, without any training. In addition, after an hour of training with this device, people's abilities to hear in noisy environments doubled (Figures 1D,E) [2].

The initial results of our vibration experiments also indicate that areas in the brain that normally respond to hearing begin to respond to vibrations. We hope these findings will lead to innovations that will help the deaf and hearing-impaired to hear, in addition to helping all of us hear better in noisy environments. Could this technology be used to help people learn a second language? Could it be used in gaming or

for immersion in virtual-reality environments? The implications could be unlimited!

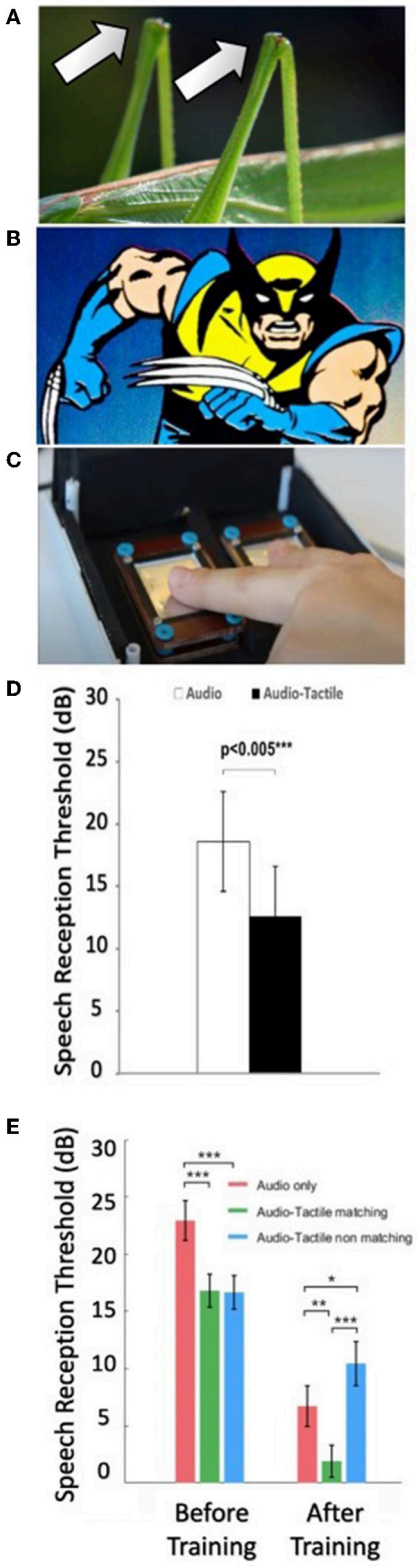

Figure 1

(A) Crickets have evolved ears on their knees, which give them excellent hearing. **(B)** The superhero Wolverine has improved senses similar to crickets. **(C)** Humans can improve their hearing by combining speech and touch, using special technology. **(D)** Our research shows that it can improve people's hearing in noisy environments with no training. **(E)** After a short training session with this device, the ability of people to hear in noisy environments was doubled (graph adapted from [2]). $*p < 0.017$, $**p < 0.003$, and $***p < 0.0003$.

HEARING TEMPERATURE

Have you ever sensed the heat of the shower before getting in, by only the sound of the running water? Research shows that you probably have but did not know it! When asked as part of a questionnaire, nearly all respondents stated they could not hear temperature. And yet, when we tested this ability by presenting people with sounds of water and asking them to choose whether the water they were hearing was hot or cold, they could identify hot or cold water with surprising accuracy.

Sensing temperature is another well-known phenomenon in nature. Snakes are known to hunt at night thanks to their ability to see heat radiating off their prey (Figures 2A,B). There is even a law called Dolbear's law that formalizes the relationship between crickets chirping and the temperature in their surroundings—they chirp faster the warmer it is. Research from our lab shows that people also learn to associate the temperature of water with the sound it makes when it is poured, without ever being taught (Figure 2C).

How do we acquire this ability? Probably through our daily multisensory interactions with pouring water. Think of how many times each day you hear water while simultaneously experiencing the temperature of it. For example, when you pour yourself some ice-cold water or make some boiling hot tea, jump into a cold swimming pool or take a hot shower in the morning. These findings made us wonder whether we could actively speed up the ability to "hear" temperature with **perceptual learning** (Figure 2D). How good could someone become at hearing temperatures if they were trained to do it? This is a subject we are currently researching.

PERCEPTUAL LEARNING

Improvements in sensory abilities resulting from experience or training.

CREATING NEW "SUPER SENSES"

What if your teacher really could see the pranks you play in class behind her back? Our lab has been studying whether we can expand the visual field to 360°, giving people the ability to see what is in front of them using their eyes, while simultaneously seeing what is behind them using another sense. This study showed that people acquire surprisingly high levels of accuracy "seeing" behind their backs when the visual information is conveyed as sounds using a **sensory substitution device** (SSD) (Figures 3A,B). This device captures a visual image using a camera and then translates the visual information into sounds, which are sent to the ears like music (Figure 3C) [3]. Our research showed that using this SSD activates the visual areas in the brain after lots of practice—showing that these areas are not used only for seeing with the eyes (Figure 3D) [4, 5]!

SENSORY SUBSTITUTION DEVICE

A device that delivers information normally acquired by one sense (for example vision) through another (for example audition or touch).

CRITICAL PERIOD

A time period in an animal's early life during which it must experience sensory stimuli so that its senses will develop normally.

In 1981, David Hubel and Torsten Wiesel won the Nobel Prize for the theory of **critical periods**, which states that the development

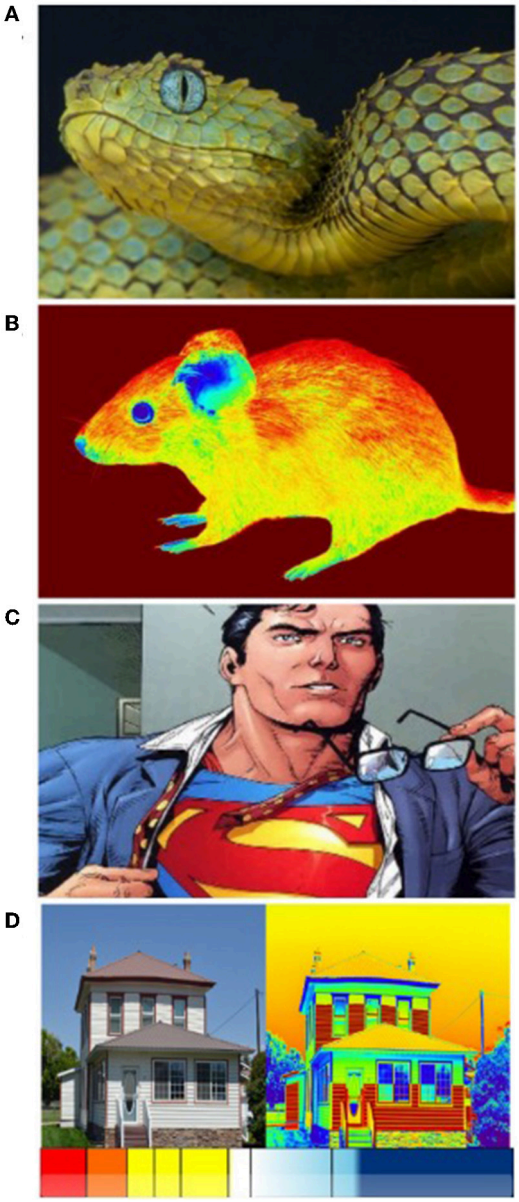

Figure 2

Figure 2

(A) Snakes have evolved thermal vision. **(B)** For 10's of 1,000's of years of evolution, they have developed the ability to see in complete darkness by detecting the heat of objects around them in infrared. **(C)** It is similar to Superman, who can shoot thermal rays out of his eyes! **(D)** We are currently investigating whether people can learn to differentiate between hot and cold water by hearing their flow, thus having a thermal sense through multi-sensory integration.

of the senses, for example, the development of normal vision or hearing, depends on the experience of visual or auditory stimuli in early childhood. They discovered that if animals did not experience a certain sense in the 1st weeks of life—the critical period—they could not develop that sense later in life. This idea is now being challenged by work done in several labs, including ours. For example, studies on children after cataract removal indicate that vision can be developed at a much older age than once was thought, so maybe there are multiple critical periods instead of only one! Moreover, if people can learn to use alternate senses, for example to "see" with their ears or "hear" through touch, or if people can learn to develop entirely new senses even in adulthood, this indicates that strict critical periods might not exist [6].

Figure 3

(A) Bats have evolved the ability to "see" with their ears. They do this using a process called echolocation, in which they emit sounds and detect them as they bounce off objects. **(B)** Daredevil, the superhero, is blind and uses echolocation to "see" sounds. **(C)** A device called the EyeMusic SSD allows people to see with sounds. **(D)** Our research shows that people who have trained using SSDs can accurately identify shapes, objects, locations, and colors [adopted from Abboud et al. [7]].

Figure 3

It seems that the more we discover about exactly how the brain is wired, the more we uncover fascinating connections between the senses that can be used to improve existing abilities and possibly to create new ones. At the beginning of the twentieth century, American psychologist William James stated that "We use only a small part of our possible mental and physical resources." The race to discover the unused resources in the brain has already begun. Who knows what we will be able to sense in the future? With the help of technology, combined with perceptual learning, we are on the verge of becoming humans with super abilities!

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REFERENCES

1. Amedi, A., Hofstetter, S., Maidenbaum, S., and Heimler, B. 2017. Task selectivity as a comprehensive principle for brain organization. *Trends Cogn. Sci.* 21:307–10. doi: 10.1016/j.tics.2017.03.007
2. Cieśla, K., Wolak, T., Lorens, A., Mentzel, M., Skarżyński, H., and Amedi, A. 2022. Effects of training and using an audio-tactile sensory substitution device on speech-in-noise understanding. *Sci. Rep.* 12:3206. doi: 10.1038/s41598-022-06855-8
3. Abboud, S., Maidenbaum, S., Dehaene, S., and Amedi, A. 2015. A number-form area in the blind. *Nat Commun.* 6:1–9. doi: 10.1038/ncomms7026
4. Maimon, A., Yizhar, O., Buchs, G., Heimler, B., and Amedi, A. 2022. A case study in phenomenology of visual experience with retinal prosthesis versus visual-to-auditory sensory substitution. *Neuropsychologia*. 2022:108305. doi: 10.1016/j.neuropsychologia.2022.108305
5. Arbel, R., Heimler, B., and Amedi, A. 2022. Congenitally blind adults can learn to identify face-shapes *via* auditory sensory substitution and successfully generalize some of the learned features. *Sci. Rep.* 12:4330. doi: 10.1038/s41598-022-08187-z
6. Hofstetter, S., Zuiderbaan, W., Heimler, B., Dumoulin, S. O., and Amedi, A. 2021. Topographic maps and neural tuning for sensory substitution dimensions learned in adulthood in a congenital blind subject. *NeuroImage*. 235:118029. doi: 10.1016/j.neuroimage.2021.118029
7. Abboud, S., Hanassy, S., Levy-Tzedek, S., Maidenbaum, S., and Amedi, A. 2014. EyeMusic: Introducing a "visual" colorful experience for the blind using auditory sensory substitution. *Restor Neurol Neurosci*. 32:247–57. doi: 10.3233/RNN-130338

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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"ORT DAFNA" MIDDLE SCHOOL, KIRYAT BIALIK, AGE: 13

We are a 7th grade class for scientific and technological leadership in the ORT Dafna Middle School in Kiryat Bialik. The class is made up of outstanding students with high scientific and mathematical affinity. We are a curious class who loves to discover new things.

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Amber Maimon is a researcher at the Baruch Ivcher Institute for Brain, Cognition, and Technology and the Ruth and Meir Rosenthal Center for Brain Imaging, directed by Prof. Amir Amedi at Reichman University. She explores the hidden connections between the senses (and their connections to the body and mind) and how these connections can be used to help people both healthy people and those with mental and physical difficulties to develop their abilities. In her free time, she likes to read, learn new things, and spend time with her family. *amber.maimon@post.idc.ac.il

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Prof. Amir Amedi is a pioneer in the study of brain plasticity and multisensory integration. In recent years, he established the Baruch Ivcher Institute for Brain, Cognition, and Technology, and the Ruth and Meir Rosenthal Center for Brain Imaging, both at Reichman University. Prof. Amedi's institute is unique in that it uses science to explore how the senses perceive stimuli and how the brain interprets them, while it also strives to move beyond the boundaries of the laboratory, using the knowledge acquired there to benefit humanity. In his free time, Prof. Amedi likes to play the saxophone with his band, travel and explore nature with his family in Israel and around the world, and spend time with his two daughters—Shir (8) and Shaked (11), to whom he dedicates this article.