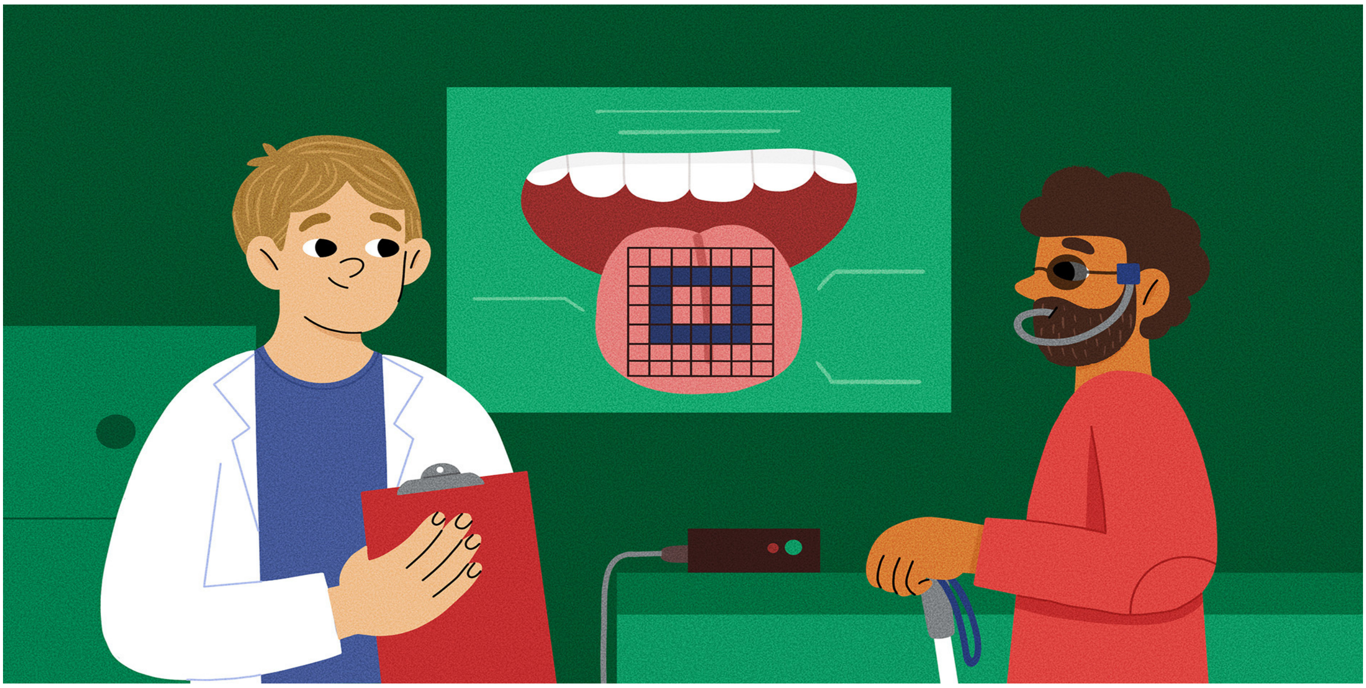
NEUROSCIENCE AND PSYCHOLOGY
Published: 30 November 2023
doi: 10.3389/frym.2023.995397



SEEING WITH YOUR TONGUE? HOW THE BRAIN USES MULTIPLE SENSES AT ONCE

Richard Augenstein*, Kayja Collett, Kaamya Mehra and Jay Hegdé

Department of Neuroscience and Regenerative Medicine, Medical College of Georgia, Augusta University, Augusta, GA, United States

YOUNG REVIEWERS:

HELENA
AGE: 15

JINYI
AGE: 8

Humans have seven main senses, each of which has its own unique sensory organs. These organs relay different kinds of information about the outside world (sights, sounds, etc.) to the brain. The information the sensory organs relay is then combined together throughout the brain. This combining of information from multiple senses is known as multisensory integration, and this is how healthy brains operate. However, for some people with a condition called synesthesia, activating a single sense (for instance, sight alone) can trigger multiple sensations such as sight *and* sound. Researchers are investigating how to use multisensory integration to help patients who have lost the ability to use one of their senses. For example, in blind patients, information from a healthy sense like the sense of touch could be used to make up for decreased vision. This is an exciting area of current and future research.

THE SEVEN SENSES

The human body has seven primary senses: vision, hearing, taste, touch, smell, **visceral sense**, and **vestibular sense** (Figure 1A). The first five are commonly known, but you may not have heard of the last two. The visceral sense is made up of sensors in and around the internal organs, which allow you to sense what is happening inside your body [1]. This can include the feeling of a full stomach, recognizing a pounding heartbeat, or feeling the need to use the bathroom. The vestibular system is found deep within the inner ear, but it is not related to hearing. Instead, it comes into play when we move. It is the system that keeps track of balance, speed, and direction of movement [2]. The vestibular sense helps you to walk, run, skateboard, or do somersaults without falling down.

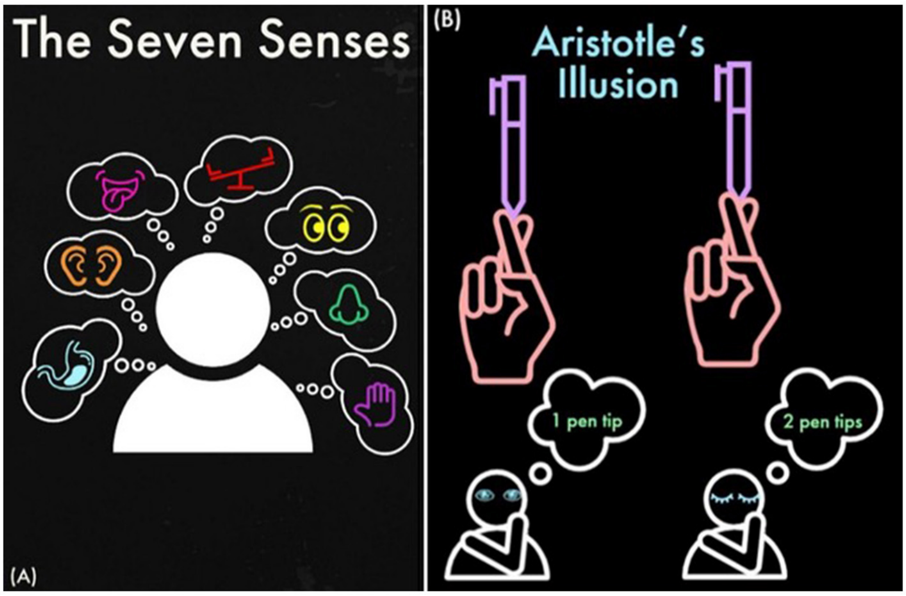


Figure 1

BRINGING THE SENSES TOGETHER: ARISTOTLE'S ILLUSION

The brain combines information from all seven senses, in a process called **multisensory integration**. You can demonstrate some of the principles of multisensory integration using an illusion first described by the Greek philosopher Aristotle (384–322 B.C.). Cross your pointer finger and middle finger and gently touch the intersection of the figures with the tip of a pen, as shown in Figure 1B. When you are looking right at it, you will feel of course a single pen tip. But when you close your eyes or ask someone else to touch the intersection of your fingers while you keep your eye closed, you are likely to feel *two* pen tips!

VISCERAL SENSE

The sensations we receive from within our body cavity, such fullness of the stomach, chest pain, or the need to use the bathroom.

VESTIBULAR SENSE

Our sense of balance and of various aspects of self-movement, such as how fast we are moving and in which direction.

Figure 1

(A) The seven senses, pictured from left to right, are: visceral, hearing, taste, vestibular, sight, smell, and touch. **(B)** Experiencing Aristotle's illusion. Cross your forefinger and middle finger and place the tip of a pen in between them, as shown. Close your eyes and let the sensation of the pen sink in. How many pen tips do you feel? Many people feel two. Now, open your eyes. How many pen tips do you feel? You mostly likely only feel one pen on both fingers in this case. This shows how combining senses (in this case sight and touch) can lead to different perceptions of reality.

MULTISENSORY INTEGRATION

The process by which the brain puts together information it receives from multiple senses into a single sensation.

PROPRIOCEPTION

The natural awareness of the body's position and movement.

This happens because crossing your fingers takes them out of their normal position—something the brain is aware of by using an aspect of the sense of touch called **proprioception**. When your eyes are closed, the brain cannot access visual information and must rely solely on proprioceptive information. The brain finds it hard to imagine that the pen could be touching the thumb side of the pointer finger and the pinky side of the middle finger at the same time. Therefore, the brain figures that there must be two different pen tips touching each of the two fingers.

When your eyes are open you still use proprioception, but the visual information tells the brain that there is only one pen tip. The brain "believes" the visual information over the proprioceptive information because the brain tends to favor vision over other senses in most cases. When your eyes are shut, your brain does its best to combine the information from the other, less favored senses, leading to a different conclusion.

HOW DOES THE BRAIN COMBINE THE INFORMATION FROM MULTIPLE SENSES?

We often think that our senses work independently of each other. However, while they *can* operate each by themselves, the natural function of the brain is to use the senses *together* to accurately perceive the world. But how does the brain do this?

SUPERIOR COLLICULUS

A small pea-sized organ deep inside the brain, one on each side. Among other things, it helps the brain combine information from multiple senses.

NEURON

A cell of the brain or nervous system that can transmit electrical signals that allow cells to communicate or that can transmit sensations from the senses to the brain.

Multisensory integration occurs throughout much of the brain, with each brain region playing a slightly different role in the process. The **superior colliculus** (SC) is a great example of how the brain combines information from multiple senses. We have two SCs: one on each side, deep in the brain. Each SC resembles a pea-sized bump and has two distinct layers of brain cells called **neurons** that receive visual, auditory (sound-based), and physical touch information. The surface layer takes in visual information, while the deep layer takes in auditory input and physical sensations [3]. This tells us that information from multiple senses overlaps in the SC. But how is the information *actually* combined?

The answer to this came from a groundbreaking study done in 1983 [4], in which researchers inserted slender, sturdy metal wires called electrodes in the SCs of cats and hamsters to measure electrical activity of individual SC neurons (Figure 2A) (these animal research procedures are carried out only when absolutely necessary to help advance science and medicine for the greater public good. Every precaution is taken to minimize the pain and discomfort felt by the animals). The researchers found that not only did a single neuron respond to both sight and sound information, but the combination of these two senses actually led to even greater electrical activity than was seen with either sense alone (Figure 2B).

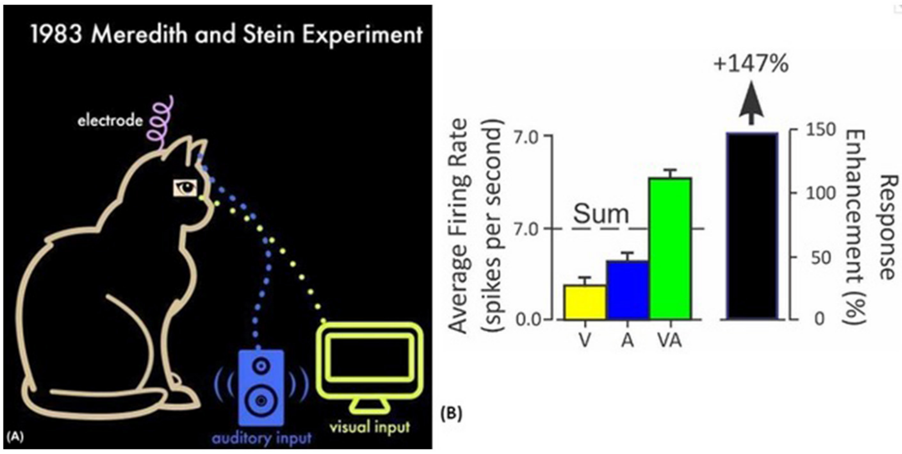


Figure 2

Figure 2

(A) To understand how the brain combines visual and auditory information, researchers used electrodes inserted into the brains of cats to measure the responses of individual SC neurons. **(B)** The graph shows the response of a single SC neuron to visual (V) or auditory (A) stimuli. The neuron's response to both stimuli presented together (VA) was greater than its responses to V alone added to the response to A alone. That is, the response to the VA stimulus was enhanced by about 147% compared to either stimulus alone. This means that the neuron was signaling specifically that *both kinds* of information were received at the same time.

This heightened response tells the brain that both visual and auditory information were received at the same time, which makes it easier for us to pick out important stimuli happening around us. For instance, it is easier to recognize someone in a crowd if you both see them *and* hear their voice, rather than just seeing them or just hearing them. Thus, neurons such as this that respond differently based on which of the senses are being stimulated help the brain combine information from multiple senses. Neurons in other regions of the brain combine information from other senses. Together, all these neurons help the brain combine information from all the senses.

CAN SOME PEOPLE REALLY *HEAR* COLORS?

So, now we know that our senses are not truly independent from one another in the brain. Although multisensory integration is a natural mechanism in the brains of all people, a small number of people (about 3%–4%) show a very unique connection between the senses called **synesthesia**. In synesthesia, stimulating one sense triggers not only that sensation but also a separate sensation of a different sense. For instance, in someone without synesthesia, hearing a sound activates the auditory system. However, a person with synesthesia (called a synesthete) whose brain connects the auditory and visual systems in a certain way will hear a sound *and* see a color. This sensory connection stays the same throughout the lifetime of the synesthete.

SYNESTHESIA

A mental condition in which stimulation of one sensory faculty is experienced as the stimulation of that sensory faculty and of a different sensory faculty.

CHROMESTHESIA

A mental condition in which those who have the condition experience sounds as both sounds and visual sensations, such as color or shapes.

Though synesthesia provides no known evolutionary advantage for survival, it may provide a great artistic advantage. Many brilliant artistic minds are known to have synesthesia, including Pharrell Williams and Billy Joel [5]. Historians now believe that Vincent van Gogh was also a synesthete [5]. All three of these famous artists have/had a particular type of synesthesia called **chromesthesia**, which is the association of sounds with colors. As musical artists, Pharrell Williams and Billy Joel "see" their music, so they can form melodies that have pleasing colors. In the case of van Gogh (1853–1890), a remarkable painter, sounds would form pictures in his mind, and he would use his talents to convey them on a canvas. Thus, multisensory integration can allow synesthetes to create unique things that they might not have created if they had experienced the world in an "ordinary" way.

USING THE TONGUE TO HELP BLIND PEOPLE "SEE"

Imagine being blind but still being able to "see" letters, objects, and obstacles. Does this sound impossible? A company based in Wisconsin (U.S.A.) created a medical device called a tongue display unit (TDU), which allows blind patients to "see" [1]. The device consists of a handheld unit connected to a camera and a tongue stimuluator. The patient wears the camera on their head, usually like eyeglasses. When the camera detects an image, the tiny vibrating dots on the tongue stimulator reflect the image (Figure 3A). When they want to see, the patients simply put the TDU on their tongue like a lollipop (Figures 3B, C). The tongue is used because it is much more sensitive to the touch than most other parts of the body [6]. The brighter parts of the image generate stronger sensations on the tongue, while darker portions produce weaker sensations. By stimulating the sense of touch this way, the blind person can use the sensations to figure out what they are "seeing." This allows them to read, find objects, navigate through obstacles, and possibly go through life with little assistance.

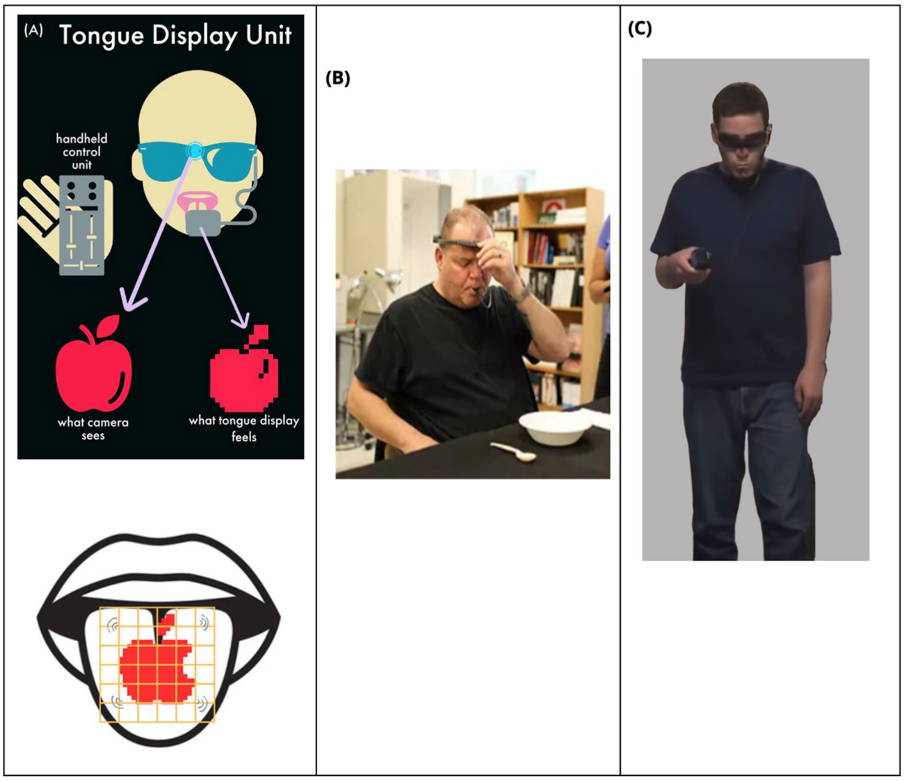


Figure 3

Figure 3

(A) The camera of a TDU records a live feed of the apple. The patient can control the orientation of the camera with the handheld unit. The TDU converts the camera image into tiny vibrations on the tongue, *via* its 144 vibrating sensors. The strength of the vibration corresponds to brightness of the image—stronger impulses for brighter portions of the image, weaker impulses for darker portions. **(B)** A blind patient uses the TDU to detect which utensils and dishes are in front of him. **(C)** A patient uses a TDU to navigate through a hallway based only on sensations received by the tongue.

Both patients who are blind from birth and those who develop visual impairments after birth can use TDUs. However, those who are blind from birth will likely need more practice, since they do not have any visual memories of objects. The sensations produced by the TDU are the same for any person, but the way the brain makes sense of them is different based on each person's memories. Blind patients report perceiving scenes with the TDU very vividly, but it is impossible to know if the sensations they experience are similar to what everyone else sees. The potential to interpret visual sensations without the ability to see using the eyes is a major breakthrough for the treatment of disabilities, and could possibly even be used to enhance the sight of people with normal vision.

CONCLUSION

Much remains to be discovered about how the brain combines information from multiple senses, and how we can take advantage of this brain faculty to help patients with one or more defective senses. This is likely to remain an exciting area of research when some of today's young readers become tomorrow's cutting-edge researchers.

ACKNOWLEDGEMENTS

Author KC designed and drew Figures 1A,B, 2A, and 3A. RA, KC, and KM were supported by the Undergraduate Research Apprenticeship Program of the U.S. Army Educational Outreach Program. Research in JH's laboratory has been supported by the Army Research Office (ARO) grant #W911NF-15-1-0311 to JH. Figure 2B was adapted from Figure 15.4 of Calvert et al. [4] by permission of The MIT Press; all rights reserved. We would also like to thank BrainPort Vision for providing the picture in Figure 3B and the University of Pittsburgh Medical Center for providing the picture in Figure 3C. Written informed consent was obtained from the individual(s) for the publication of any identifiable images or data included in this article.

REFERENCES

1. De Lahunta, A., and Glass, E. (eds). 2009. "Chapter 16 - Visceral afferent systems," in *Veterinary Neuroanatomy and Clinical Neurology*, 3rd ed. (Gainesville, FL: Saunders Elsevier), 441-447.
2. Gray, L. 2020. *Neuroscience Online*. Houston, TX: University of Texas McGovern Medical School.
3. Zubricky, R. D., and Das, J. M. 2022. *Neuroanatomy, Superior Colliculus.* In StatPearls. Treasure Island, FL: StatPearls Publishing.
4. Calvert, G., Spence, C., and Stein, B. E. 2004. *The Handbook of Multisensory Processes*. Cambridge, MA: MIT Press, xvii, 915.

5. English, T. 2019. *9 Famous Artists Who Have Synesthesia and How It Affected them*. Available online at: https://interestingengineering.com/lists/9-famous-artists-who-have-synesthesia-and-how-it-affected-them (accessed November 19, 2023).
6. Tenenbaum, D. 2016. *A Taste of Vision: Device Translates from Camera to Brain, via the Tongue*. Available online at: https://news.wisc.edu/a-taste-of-vision-device-translates-from-camera-to-brain-via-the-tongue/ (accessed November 19, 2023).

SUBMITTED: 15 July 2022; **ACCEPTED:** 08 November 2023;
PUBLISHED ONLINE: 30 November 2023.

EDITOR: Daniel W. Wesson, University of Florida, United States

SCIENCE MENTORS: Ingo Sasgen and Zheng Jin

CITATION: Augenstein R, Collett K, Mehra K and Hegdé J (2023) Seeing With Your Tongue? How The Brain Uses Multiple Senses At Once. Front. Young Minds 11:995397. doi: 10.3389/frym.2023.995397

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.

YOUNG REVIEWERS

HELENA, AGE: 15
My name is Helena and I am 15 years old. I spent 2 years in the US when I was younger where I discovered my passion for the English language. I love writing and listening to poems, and longer bike trips. I am also incredibly fascinated by all sorts of sciences but particularly genetics, microbiology, neuroscience, and psychology.

JINYI, AGE: 8
Hello, I am Jinyi, and I have given myself an English name, Joey. I am from Zhengzhou, China, and I am now 8 and half years old. I love eating mangoes. I enjoy watching the Japanese manga series called Demon Slayer: Kimetsu no Yaiba. I also enjoy family trips. I have been to Japan and South Korea several times, and my next stops are the United States and Europe. I enjoy doing crafts and playing the piano. I hope my works can bring joy to more people.

AUTHORS

RICHARD AUGENSTEIN

Richard is a first year graduate student at the University of Georgia. He is pursuing his M.S. in exercise psychology under Patrick O'Connor, Ph.D. He worked in Dr. Jay Hegdé's neuroscience lab in 2022, and enjoyed learning about the brain and its incredible abilities. In his free time, he loves listening to and making music, exercising, and cheering for his favorite American college football team, the Georgia Bulldogs. *pianorich2000@gmail.com

KAYJA COLLETT

Kayja is a third-year undergraduate student at Georgia State University. She is majoring in neuroscience with a concentration in pre-med. She enjoys learning about the brain, body, and how they connect. She is grateful for the opportunity to have worked in Dr. Hegdé's lab as an apprentice. She wants to go to medical school to specialize in either pediatric neurology or neurophysiology. Her outside interests include baking, reading, and water sports. She is currently planning her wedding and excited for the future with her new husband.

KAAMYA MEHRA

Kaamya is a sophomore undergraduate student at Augusta University. She is majoring in cell and molecular biology as a part of the Professional Scholars BS/MD program. She enjoys learning about neuroscience and hopes to be a physician in the future. She enjoys dancing, trivia, playing sports, spending time with friends, and reading. She worked for Dr. Jay Hegdé as an apprentice, researching multisensory perception and other neuroscience concepts.

JAY HEGDÉ

Dr. Jay Hegdé is a brain researcher at the Medical College of Georgia of Augusta University (USA). His research focuses on understanding how our brains function under real-world conditions. In his spare time, he seeks to understand why some youngsters grow up to become smart, righteous good-looking people who root for the New York Yankees baseball team, while other perfectly innocent kids, through no fault of their own, grow up to become fans of the Boston Red Sox baseball team. Based on his experiences with Red Sox fans, Jay is writing two books: "Why Drinking is Not the Same Thing as Showering," and "Red Sox Dreams: Having Teeth and Brushing Them Too."