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Visual Perception for the Blind: The Brain Port Vision Device

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ABSTRACT

The BrainPort Vision Device allows the blinds to "see" using their tougues. The device includes a pair of sunglassess that has a tiny digital video camera for collecting visual data. Data collected are then transmitted to a handheld, cellphone-sized base unit that will convert digital signal into electrical pulses.

Converted signals will be sent to the tongue via a "lollipop", an electrode array about nine square centimeters that sits directly on the tongue. This amazing new device may help people to interact with their environment in ways never before experiences.

Introduction

A new device to help the blind see has been developed by scientists. It is manufactured by Wicab, a biomedical engineering company focused on developing and testing the brain port vision device. The electric lollipop or Brain Port vision device captures images using a tiny camera and then converts the image into tiny tingles on the tongue. The tingles are then sent to the brain which then converts the tingles into pictures. After a few days practicing people, who otherwise couldn't see, were able to make out shapes, read signs and even read letters. This amazing new device may help people to interact with their environment in ways never before experiences.

Using the unique resources of the DOE national laboratories in materials sciences, micro fabrication, microelectrode construction, photochemistry and computer modelling, the project's goal is to construct the device, capable of restoring vision, with materials that will last for the lifetime of a blind person. Just as blind people read words by touching Braille bumps, some are now able to "see" objects via a special lollipop that stimulates their taste buds. The extraordinary device converts images captured by a tiny camera into a series of electrical tingles, which can be felt on the tongue.

Nerves then send these messages to the brain, which turn the tingles back into pictures.

Visual data is collected from a video camera about 1.5cm in diameter that sites in centre of a pair of sunglasses worn by the user. Bypassing the eyes, the data are transmitted to a handheld base unit which has features such as zoom control, light settings, shock intensify level and central processing unit (CPU). The job of this device is to interpret the information that it receives through stimulation device and use it like data from natural sense. Research from prototype devices showed such training is possible, as patients with severe bilateral vestibular loss could, after time, maintain near-normal posture control while sitting and walking, even on uneven surfaces. Thus if proper training is given to patients they can perceive size, shape, location and motion of objects in environment The device uses concept of electro tactile stimulation for sensory substitution. The idea is to communicate nontactile via electrical

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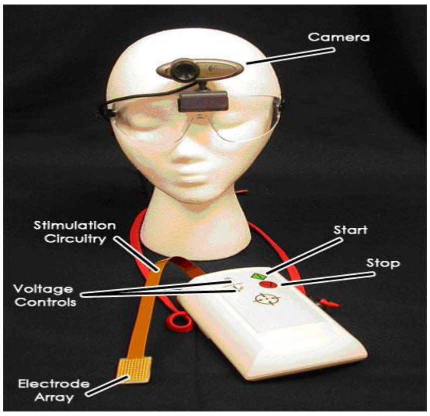
stimulation of the sense of touch. In practice, this typically means that "an array of electrodes receiving input from a non- tactile information source (a camera, for instance) applies small, controlled, painless currents (some subjects report it feeling something like soda bubbles) to the skin at precise locations according to an encoded pattern." For a blind person, it means the encoding of the electrical pattern essentially attempts to mimic the input that would normally be received by the non-functioning sense – vision. So patterns of light picked up by a camera to form an image are replacing the perception of the eyes and converted into electrical pulses that represent those patterns of light. In other words, when the encoded pulses are applied to the skin, the skin is actually receiving image data which would be then sent to the brain in the forms of impulse. Under normal circumstances, the parietal lobe in the brain receives touch information, while the occipital lobe receives vision information] When the nerve fibers forward the image encoded touch signals to the parietal lobe, "the electric field thus generated in subcutaneous tissue directly excites the afferent nerve fibres responsible for touch sensations". Within the system, arrays of electrodes can be used to communicate non-touch information through pathways to the brain normally used for the touch related impulses. The breakthrough of the Brain port technology is to use the tongue as the substitute sensory channel. Through this paper we would like to make the reader aware of this brilliant technology and broaden his/her perspective on this device; for our goal is to plant the seed of curiosity in the reader so that he/she is compelled to thinthem (Figure 1). The benefits include increased independence, improved safety, mobility, object recognition and the ability to apply the technology toward specific hobbies and recreational situations. Past users have used the device to read words, play games such as tic-tac-toe, build a snowman etc

CAUSE FOR THE NEED:

Individuals with LP or NLP vision are among the most challenging, and heartbreaking, patients we encounter. Our ability to improve their circumstances is woefully limited. Any efforts that can provide them with some gain in sensory input will improve their independence, and with it, their quality of life.

The BrainPort vision device is an investigational, non-surgical visual prosthetic that translates information from a digit al video camera to the user's tongue, using gentle electrical stimulation. With training, totally blind users learn to interpret the images on their tongue as information about the scene in front of them **(Figure 1).** The benefits include increased independence, improved safety, mobility, object recognition and the ability to apply the technology toward specific hobbies and recreational situations. Past users have used the device to read words, play games such as tic-tac-toe, build a snowman etc.



To produce **tactile vision**, BrainPort uses a camera to capture visual data. The optical information --

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light that would normally hit the retina -- that the camera picks up is in digital form, and it uses radio signals to send the

ones and zeroes to the CPU for encoding. Each set of pixels in the camera's light sensor corresponds to an electrode in the array. The CPU runs a program that turns the camera's electrical information into a spatially encoded signal. The encoded signal represents differences in pixel data as differences in pulse characteristics such as frequency, amplitude and duration. Multidimensional image information takes the form of variances in pulse current or voltage, pulse duration, intervals between pulses and the number of pulses in a burst, among other parameters. According to U.S. Patent 6,430,450, licensed to Wicab for the BrainPort application:

To the extent that a trained user may simultaneously distinguish between multiple of these characteristics of amplitude, width and frequency, the pulses may convey multidimensional information in much the same way that the eye perceives color from the independent stimulation of different color receptors.

The electrode array receives the resulting signal via the stimulation circuitry and applies it to the tongue. The brain eventually learns to interpret and use the information coming from the tongue as if it were coming from the eyes.

After training in laboratory tests, blind subjects were able to perceive visual traits like looming, depth, perspective, size and shape. The subjects could still feel the pulses on their tongue, but they could also perceive images generated from those pulses by their brain. The subjects perceived the objects as "out there" in front of them, separate from their own bodies. They could perceive and identify letters of the alphabet. In one case, when blind mountain climber Erik Weihenmayer was testing out the device, he was able to locate his wife in a forest. One of the most common questions at this point is, "Are they really seeing?" That all depends on how you define vision. If seeing means you can identify the letter "T" somewhere outside yourself, sense when that "T" is getting larger, smaller, changing orientation or moving farther away from your own body, then they're really seeing. One study that conducted PET brain scans of congenitally blind people while they were using the BrainPort vision device found that after several sessions with BrainPort, the vision centers of the subjects' brains lit up when visual information was sent to the brain through the tongue. If "seeing" means there's activity in the vision center of the cerebral cortex, then the blind subjects are really seeing.

The BrainPort vision system consists of a postage-stamp–sized array of 400 electrodes placed on the top surface of the tongue **(Figure 2),** a digital video camera affixed to a pair of sunglasses and a hand-held controller for settings, such as zoom and control of the stimulation level. Visual information is collected from the user-adjustable head-mounted camera (field of view 3° to 73°) and is sent to the BrainPort handheld controller.

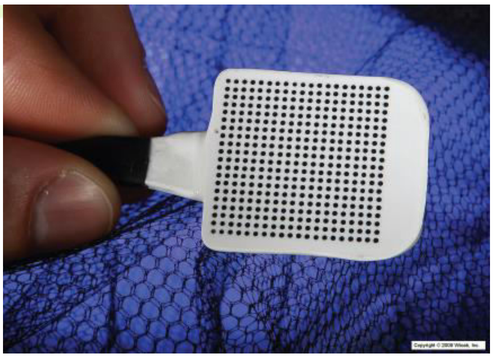

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Figure 2. The BrainPort vision system consists of a postage-stamp–sized array of 400 electrodes placed on the top surface of the tongue.

The controller translates the visual information into a stimulation pattern that is displayed on the tongue. The tactile image is created by presenting white pixels from the camera as strong stimulation, black pixels as no stimulation and gray pixels as medium levels of stimulation, with the ability to invert contrast when appropriate. Users describe the perception as moving pictures drawn on their tongue with effervescing bubbles.

PATIENT SELECTION CRITERIA

The BrainPort vision device is initially being studied with individuals having no useful vision (light perception or worse), as preliminary clinical studies have confirmed successful use by these individuals. Because the BrainPort vision device requires a training period, initial users are more likely to be younger, technologically savvy and independently mobile users. Unlike other visual prosthetic technologies (retinal and cortical implants), the BrainPort provides benefits for a wide range of blindness etiologies (including both congenitally and acquired) and does not require any surgery.

How BrainPort Works

A blind woman sits in a chair holding a video camera focused on a scientist sitting in front of her. She has a device in her mouth, touching her tongue, and there are wires running from that device to the video camera. The woman has been blind since birth and doesn't really know what a rubber ball looks like, but the scientist is holding one. And when he suddenly rolls it in her direction, she puts out a hand to stop it. The blind woman saw the ball. Through her tongue.

Well, not exactly through her tongue, but the device in her mouth sent visual input through her tongue in much the same way that seeing individuals receive visual input through theeyes. In both cases, the initial sensory input mechanism -- the tongue or the eyes -- sends the visual data to the brain, where that data is processed and interpreted to form images. What we're talking about here is **electrotactile stimulation for sensory augmentation or substitution**, an area of study that involves using encoded electric current to represent sensory information -- information that a person cannot receive through the traditional channel -- and applying that current to the skin, which sends the information to the brain. The brain then learns to interpret that sensory information as if it were being sent through the traditional channel for such data. In the 1960s and '70s, this process was the subject of ground-breaking research in sensory substitution at the Smith-Kettlewell Institute led by Paul Bach-y-Rita, MD, Professor of Orthopedics and Rehabilitation and Biomedical Engineering at the University of Wisconsin, Madison. Now it's the basis for Wicab's BrainPort technology (Dr. Bach-y-Rita is also Chief Scientist and Chairman of the Board of Wicab).

Most of us are familiar with the augmentation or substitution of one sense for another. Eyeglasses are a typical example of sensory augmentation. Braille is a typical example of sensory substitution -- in this case, you're using one sense, touch, to take in information normally intended for another sense, vision. Electrotactile stimulation is a higher-tech method of receiving somewhat similar (although more surprising) results, and it's based on the idea that the brain can interpret sensory information even if it's not

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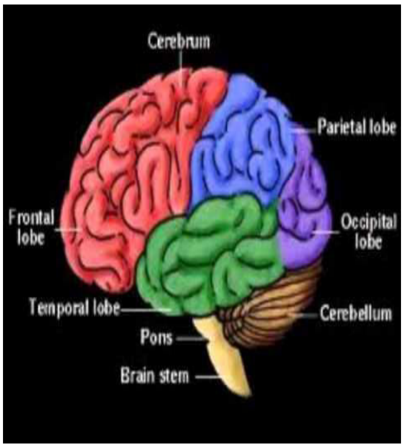
provided via the "natural" channel. Dr. Bach-y-Rita puts it this way:

We do not see with the eyes; the optical image does not go beyond the retina where it is turned into spatio-temporal nerve patterns of [impulses] along the optic nerve fibers. The brain then recreates the images from analysis of the impulse patterns.

The multiple channels that carry sensory information to the brain, from the eyes, ears and skin, for instance, are set up in a similar manner to perform similar activities. All sensory information sent to the brain is carried by **nerve fibers** in the form of **patterns of impulses**, and the impulses end up in the different sensory centers of the brain for interpretation. To substitute one sensory input channel for another, you need to correctly **encode** the nerve signals for the sensory event and send them to the brain through the alternate channel. The brain appears to be flexible when it comes to interpreting sensory input. You can train it to read input from, say, the tactile channel, as visual or balance information, and to act on it accordingly. In JS Online's "Device may be new pathway to the brain," University of Wisconsin biomedical engineer and BrainPort technology co-inventor Mitch Tyler states, "It's a great mystery as to how that process takes place, but the brain can do it if you give it the right information."

Concepts of Electrotactile Stimulation

The concepts at work behind electrotactile stimulation for sensory substitution are complex, and the mechanics of implementation are no less so. The idea is to communicate non-tactile information via electrical stimulation of the sense of touch. In practice, this typically means that an array of electrodes receiving input from a non-tactile information source (a camera, for instance) applies small, controlled, painless currents (some subjects report it feeling something like soda bubbles) to the skin at precise locations according to an encoded pattern. The encoding of the electrical pattern essentially attempts to mimic the input that would normally be received by the non-functioning sense. So patterns of light picked up by a camera to form an image, replacing the perception of the eyes, are converted into electrical pulses that represent those patterns of light. When the encoded pulses are applied to the skin, the skin is actually receiving image data. According to Dr. Kurt Kaczmarek, BrainPort technology co-inventor and Senior Scientist with the University of Wisconsin Department of Orthopedics and Rehabilitation Medicine, what happens next is that "the electric field thus generated in subcutaneous tissue directly excites the afferent nerve fibers responsible for normal, mechanical touch sensations." Those nerve fibers forward their image-encoded touch signals to the tactile-sensory area of the cerebral cortex, the **parietal lobe**.



Under normal circumstances, the parietal lobe receives touch information,

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the temporal lobe receives auditory information, the occipital lobe receivesvision information and the cerebellum receives balance information.(The frontal lobe is responsible for all sorts of higher brain functions,and the brain stem connects the brain to the spinal cord.)

Within this system, arrays of electrodes can be used to communicate non-touch information through pathways to the brain normally used for touch-related impulses. It's a fairly popular area of study right now, and researchers are looking at endless ways to utilize the apparent willingness of the brain to adapt to cross-sensory input. Scientists are studying how to use electrotactile stimulation to provide sensory information to the vision impaired, the hearing impaired, the balance impaired and those who have lost the sense of touch in certain skin areas due to nerve damage. One particularly fascinating aspect of the research focuses on how to quantify certain sensory information in terms of electrical parameters -- in other words, how to convey "tactile red" using the characteristics of electricity.

This is a field of scientific study that has been around for nearly a century, but it has picked up steam in the last few decades. The miniaturization of electronics and increasingly powerful computers have made this type of system a marketable reality instead of just a really impressive laboratory demonstration. Enter BrainPort, a device that uses electrotactile stimulation to transmit non-tactile sensory information to the brain. BrainPort uses the **tongue** as a substitute sensory channel. In the next section, we'll get inside BrainPort.

Scientists have been studying electrotactile presentation of visual information since the early 1900s, at least. These research setups typically used a camera to set current levels for a matrix of electrodes that spatially corresponded to the camera's light sensors. The person touching the matrix could visually perceive the shape and spatial orientation of the object on which the camera was focused. BrainPort builds on this technology and is arguably more streamlined, controlled and sensitive than the systems that came before it.

For one thing, BrainPort uses the **tongue** instead of the fingertips, abdomen or back used by other systems. The tongue is more sensitive than other skin areas -- the nerve fibers are closer to the surface, there are more of them and there is no stratum corneum (an outer layer of dead skin cells) to act as an insulator. It requires less voltage to stimulate nerve fibers in the tongue -- 5 to 15 volts compared to 40 to 500 volts for areas like the fingertips or abdomen. Also, saliva contains electrolytes, free ions that act as electrical conductors, so it helps maintain the flow of current between the electrode and the skin tissue. And the area of the cerebral cortex that interprets touch data from the tongue is larger than the areas serving other body parts, so the tongue is a natural choice for conveying tactile-based data to the brain.

Wicab is currently seeking FDA approval for a **balance-correction** BrainPort application. A person whose vestibular system, the overall balance mechanism that begins in the inner ears, is damaged has little or no sense of balance -- in severe cases, he may have to grip the wall to make it down a hallway, or be unable to walk at all. Some inner-ear disorders include bilateral vestibular disorders (BVD), acoustic neuroma and Meniere's disease, and the sense of balance can also be affected by common conditions like migraines

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and strokes. The BrainPort balance device can help people balance problems to retrain their brains to interpret balance information coming from their tongue instead of their inner ear with

ad of their inner ear.

BrainPort balance components simplified

An **accelerometer** is a device that measures, among other things, tilt with respect to the pull of gravity. The accelerometer on the underside of the 10-by-10 electrode array transmits data about head position to the CPU through the communication circuitry. When the head tilts right, the CPU receives the "right" data and sends a signal telling the electrode array to provide current to the right side of the wearer's tongue. When the head tilts left, the device buzzes the left side of the tongue. When the head is level, BrainPort sends a pulse to the middle of the tongue. After multiple sessions with the device, the subject's brain starts to pick up on the signals as indicating head position -- balance information that normally comes from the inner ear -- instead of just tactile information.

Wicab conducted a clinical trial with the balance device in 2005 with 28 subjects suffering from bilateral vestibular disorders (BVD). After training on BrainPort, all of the subjects regained their sense of balance for a period of time, sometimes up to six hours after each 20-minute BrainPort session. They could control their body movements and walk steadily in a variety of environments with a normal gait and with fine-motor control. They experienced muscle relaxation, emotional calm, improved vision and depth perception and normalized sleep patterns.

TRAINING

Training is provided by an orientation and mobility instructor, a low vision professional, or those with similar backgrounds in blindness rehabilitation. Training performance is monitored using an accessory that displays video from the user-mounted camera and provides a visual depiction of the stimulation pattern on the tongue **(Figure 3).** Training occurs across a variety of tasks to encourage generalized learning. New users receive at least 10 hours of training prior to independent use. Skills are expected to continue to develop beyond the initial training period.

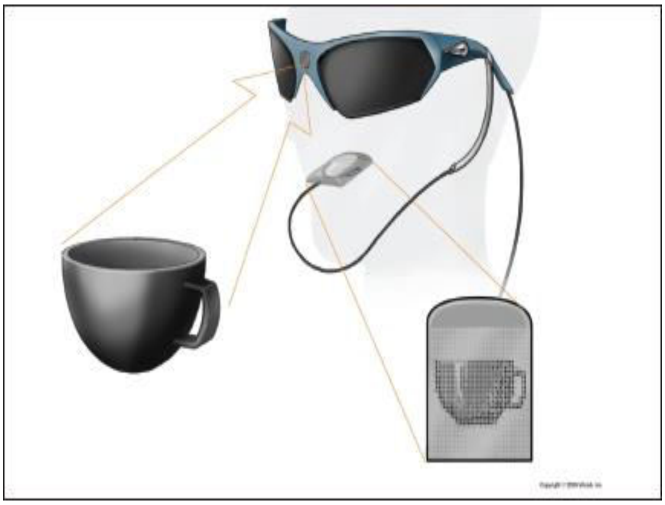

Figure 3. Training performance is monitored using an accessory that displays video from the user mounted camera (top) and provides a

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visual depiction of the stimulation pattern on the tongue (bottom).

Current and Potential Applications

While the full spectrum of BrainPort applications has yet to realized, the device has the potential to lessen an array of sensory limitations and to alleviate the symptoms of a variety of disorders. Just a few of the current or foreseeable medical applications include:

- providing elements of sight for the visually impaired
- providing sensory-motor training for stroke patients
- providing tactile information for a part of the body with nerve damage
- alleviating balance problems, posture-stability problems and muscle rigidity in people with balance disorders and Parkinson's disease
- enhancing the integration and interpretation of sensory information in autistic people

Beyond medical applications, Wicab has been exploring potential military uses with a grant from the Defense Advanced Research Projects Agency (DARPA). The company is looking into underwater applications that could provide the Navy SEALs with navigation information and orientation signals in dark, murky water (this type of setup could ultimately find a major commercial market with recreational SCUBA divers). The BrainPort electrodes would receive input from a sonar device to provide not only directional cues but also a visual sense of obstacles and terrain. Military-navigation applications could extend to soldiers in the field when radiocommunication is dangerous or impossible or when their eyes, ears and hands are needed to manage other things -- things that might blow up. BrainPort may also provide expanded information for military pilots, such as a pulse on the tongue to indicate approaching aircraft or to indicate that they must take immediate action. With training, that pulse on their tongue could elicit a faster reaction time than a visual cue from a light on the dashboard, since the visual cue must be processed by the retina before it's forwarded to the brain for interpretation.

Other potential BrainPort applications include robotic surgery. The surgeon would wear electrotactile gloves to receive tactile input from robotic probes inside someone's chest cavity. In this way, the surgeon couldfeel what he's doing as he controls the robotic equipment. Race car drivers might use a version of BrainPort to train their brains for faster reaction times, and gamers might use electrotactile feedback gloves or controllers to feel what they're doing in a video game. A gaming BrainPort could also use a tactile-vision process to let gamers perceive additional information that isn't displayed on the screen.

BrainPort is currently conducting a second round of clinical trials as it works its way through the FDA approval process for the balance device. The company estimates a commercial release in late 2006, with a roughly estimated selling price of $10,000 per unit.

Already more streamlined than any previous setup using electrotactile stimulation for sensory substitution, BrainPort envisions itself even smaller

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and less obtrusive in the future. In the case of the balance device, all of the electronics in the handheld part of the system might fit into a discreet mouthpiece. A dental-retainer-like unit would house a battery, the electrode array and all of the microelectronics necessary for signal encoding and transmitting. In the case of the BrainPort vision device, the electronics might be completely embedded in a pair of glasses along with a tiny camera and radio transmitter, and the mouthpiece would house a radio receiver to receive encoded signals from the glasses. It's not exactly a system on a chip, but give it 20 years -- we might be seeing a camera the size of a grain of rice embedded in people's foreheads by then.

CONCLUSION:

Thus brain port vision device proves a way to enlighten the visionless people using the technology.

ADVANTAGES:

- Gives information about shape, size, and location of objects.
- Users can operate it independently.
- Uses a battery that is rechargeable.

DISADVANTAGES:

- Frequent training to the brain is essential.
- Its cost is $10,000. Hence it is not affordable to the common.
- Have some side effects.

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