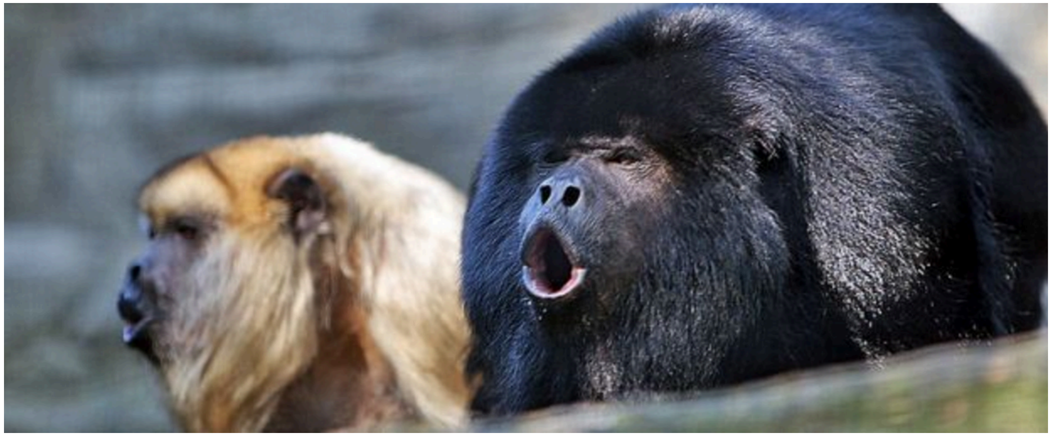
Computational Sensation and Cognition(ELL788)

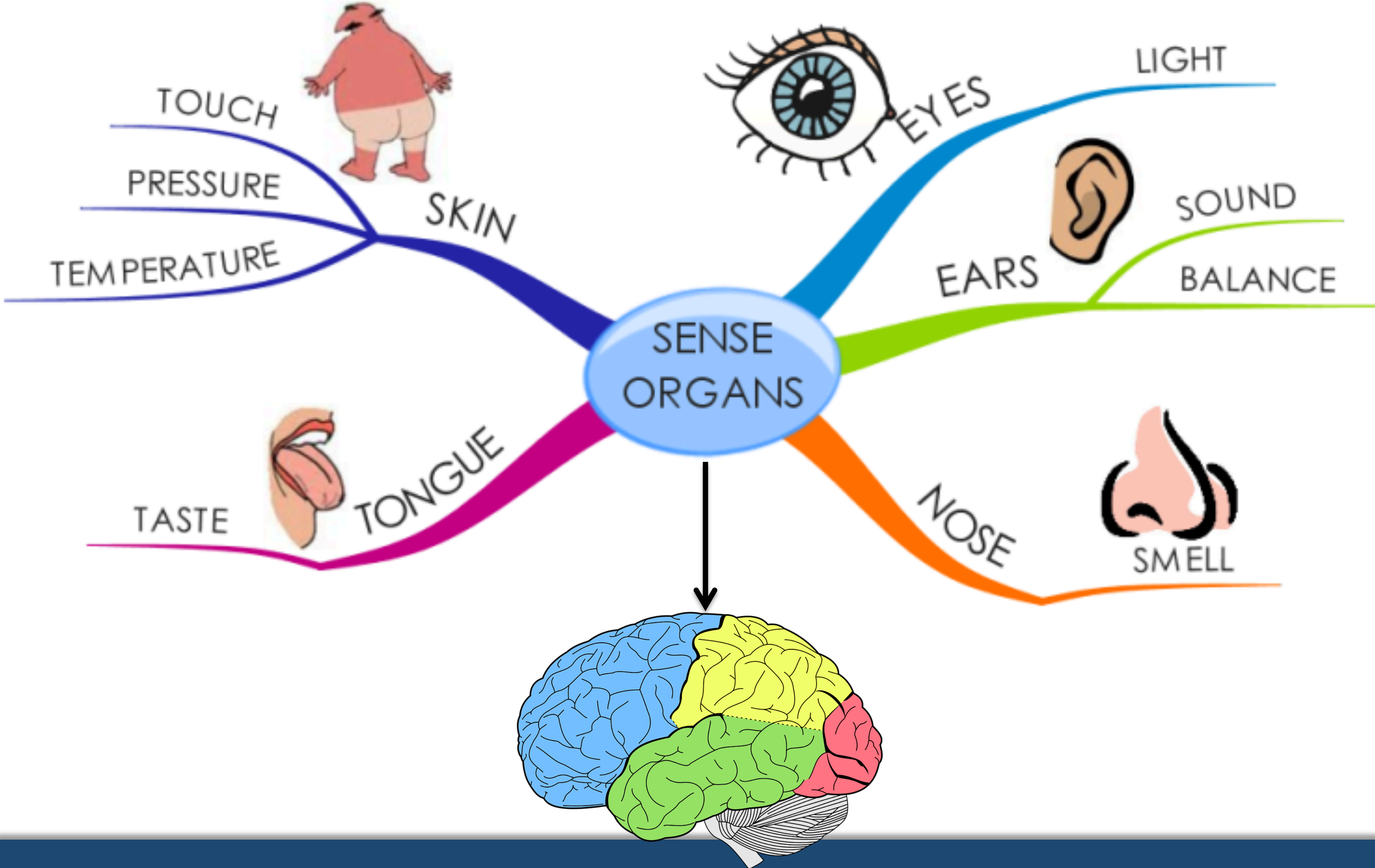


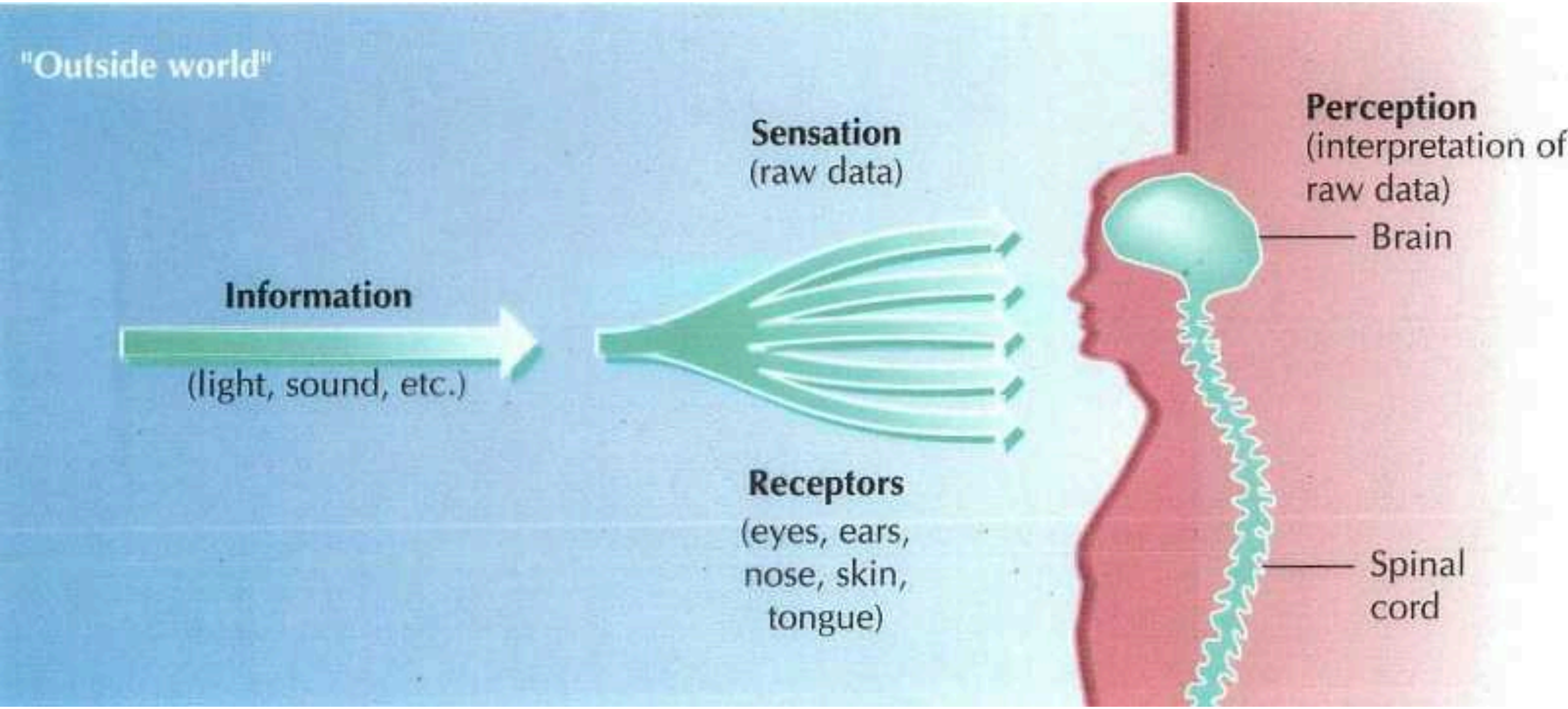
Dr Tapan K. Gandhi

Dept. of Electrical Engineering

IIT Delhi

- Sensation
- Perception
- Cognition

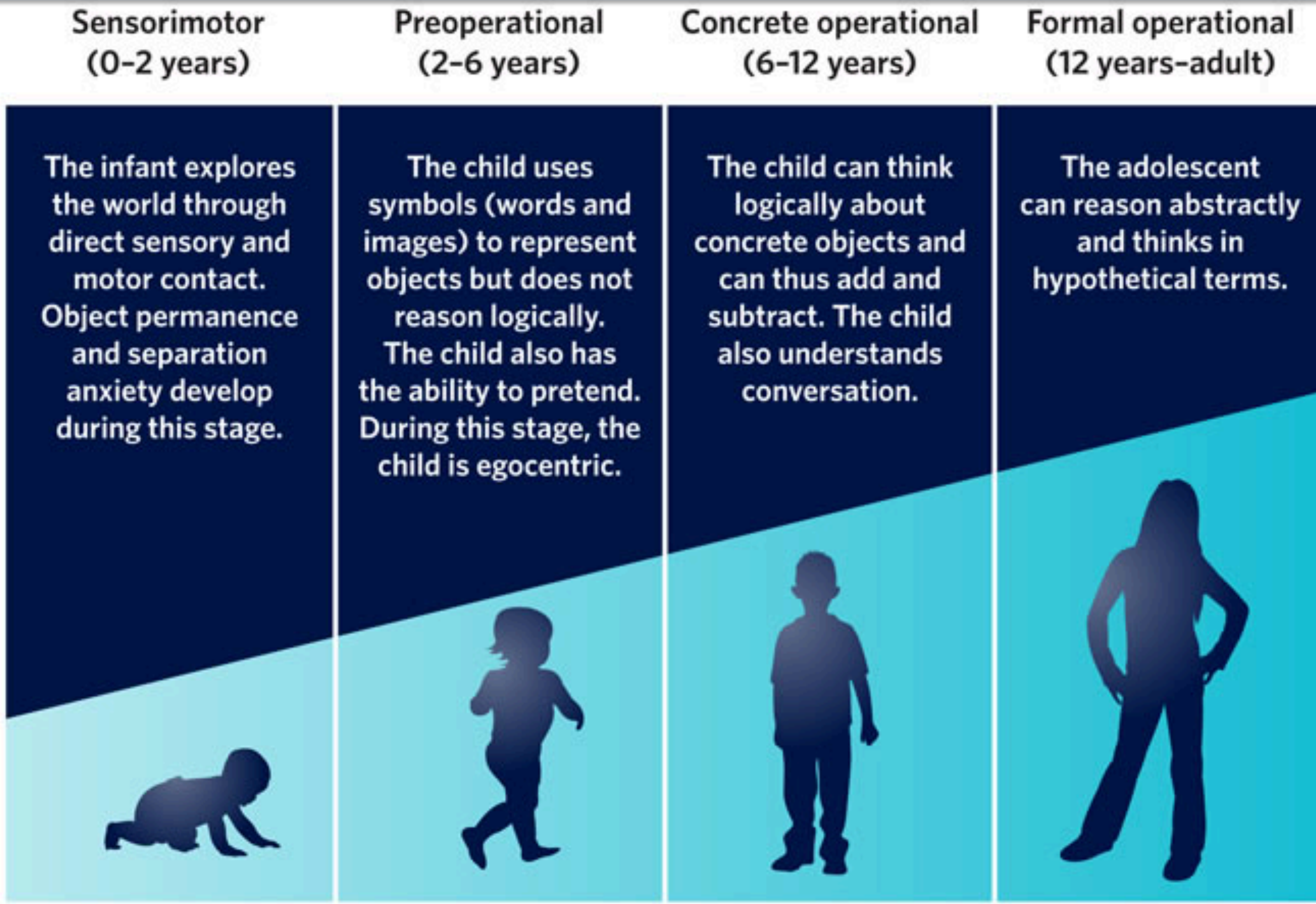

SENSE ORGANS
SKIN
TOUCH
PRESSURE
TEMPERATURE
EYES
LIGHT
EARS
SOUND
BALANCE
TONGUE
TASTE
NOSE
SMELL



"Outside world"
Information
(light, sound, etc.)
Sensation
(raw data)
Receptors
(eyes, ears,
nose, skin,
tongue)
Perception
(interpretation of
raw data)
Brain
Spinal
cord

Cognition is "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses.”

Processes such as knowledge, attention, memory and working memory, judgment and evaluation, reasoning and "computation", problem solving and decision making, comprehension and production of language, et. Are examples of Cognitive process.

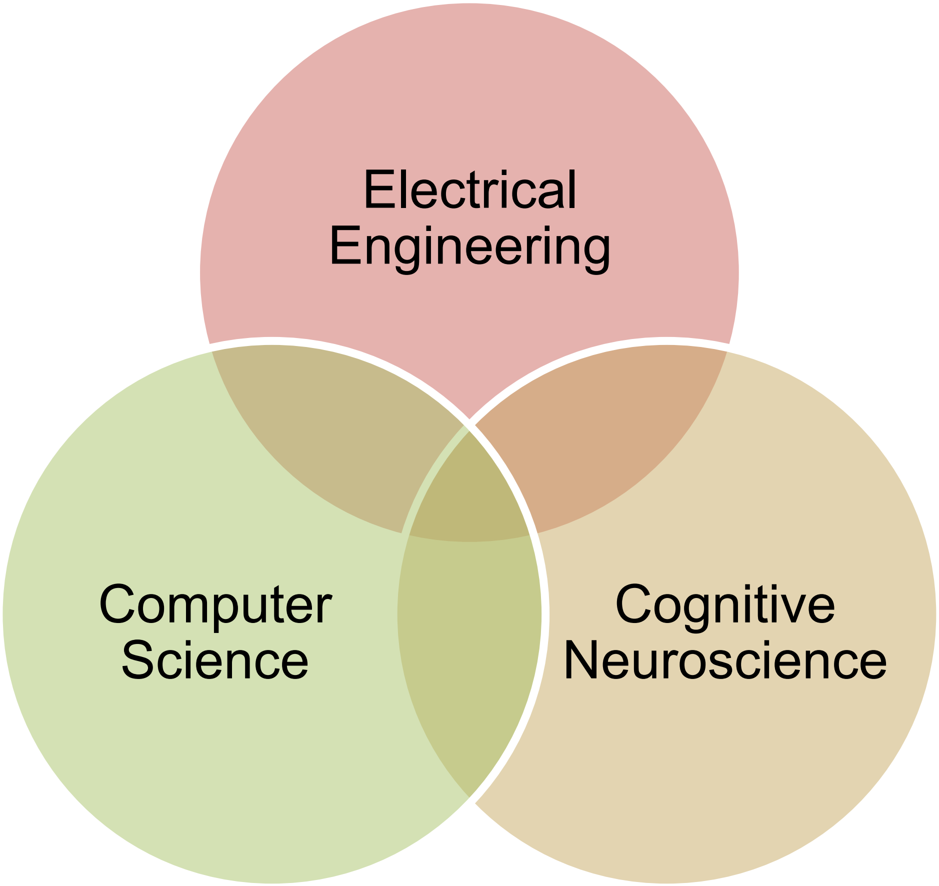

Sensorimotor
(0-2 years)
Preoperational
(2-6 years)
Concrete operational
(6-12 years)
Formal operational
(12 years-adult)
The infant explores the world through direct sensory and motor contact. Object permanence and separation anxiety develop during this stage.
The child uses symbols (words and images) to represent objects but does not reason logically. The child also has the ability to pretend. During this stage, the child is egocentric.
The child can think logically about concrete objects and can thus add and subtract. The child also understands conversation.
The adolescent can reason abstractly and thinks in hypothetical terms.

"Listening to the Brain"

Applications in Health and Engineering

Why should we listen to the brain?

- To understand how the brain develops
- To understand normal brain functioning
- To understand brain disorders



- All the non-invasive techniques yields a wealth of information that needs sophisticated analytical approaches.
- A powerful way forward is to use the techniques for signal analysis and data mining developed in electrical engineering and computer science for analyzing neural signals.

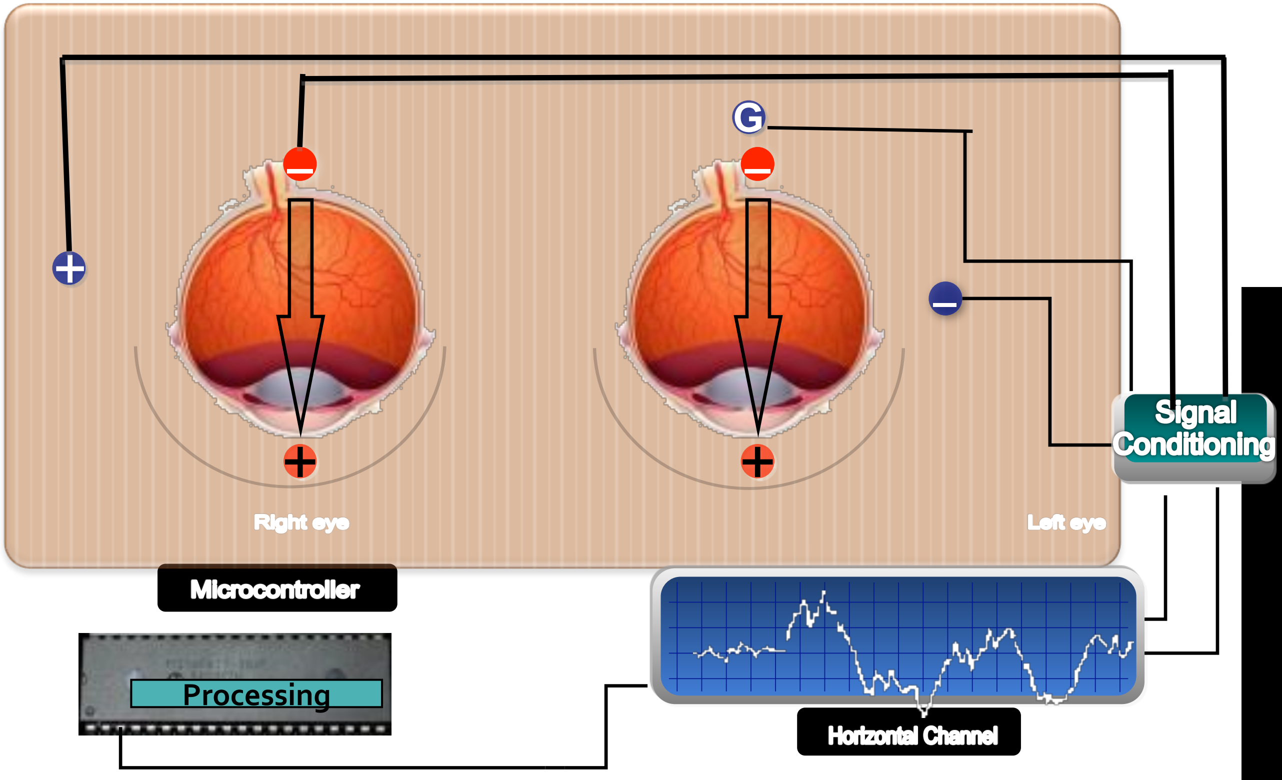
Technological Interface (Assistive Devices)

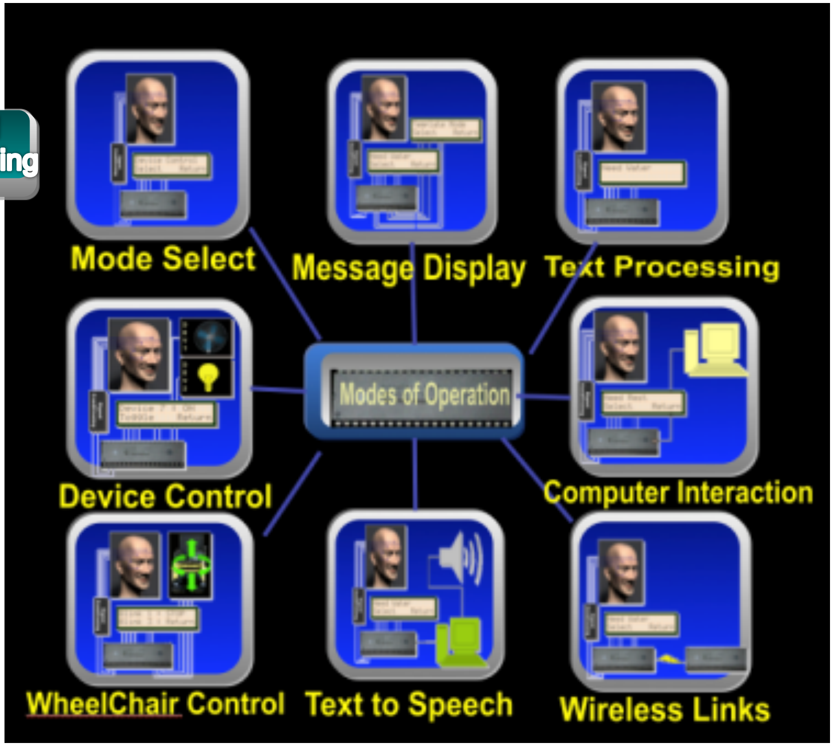
Trials at the Indian Spinal Injury Centre, New Delhi

Blow Switch

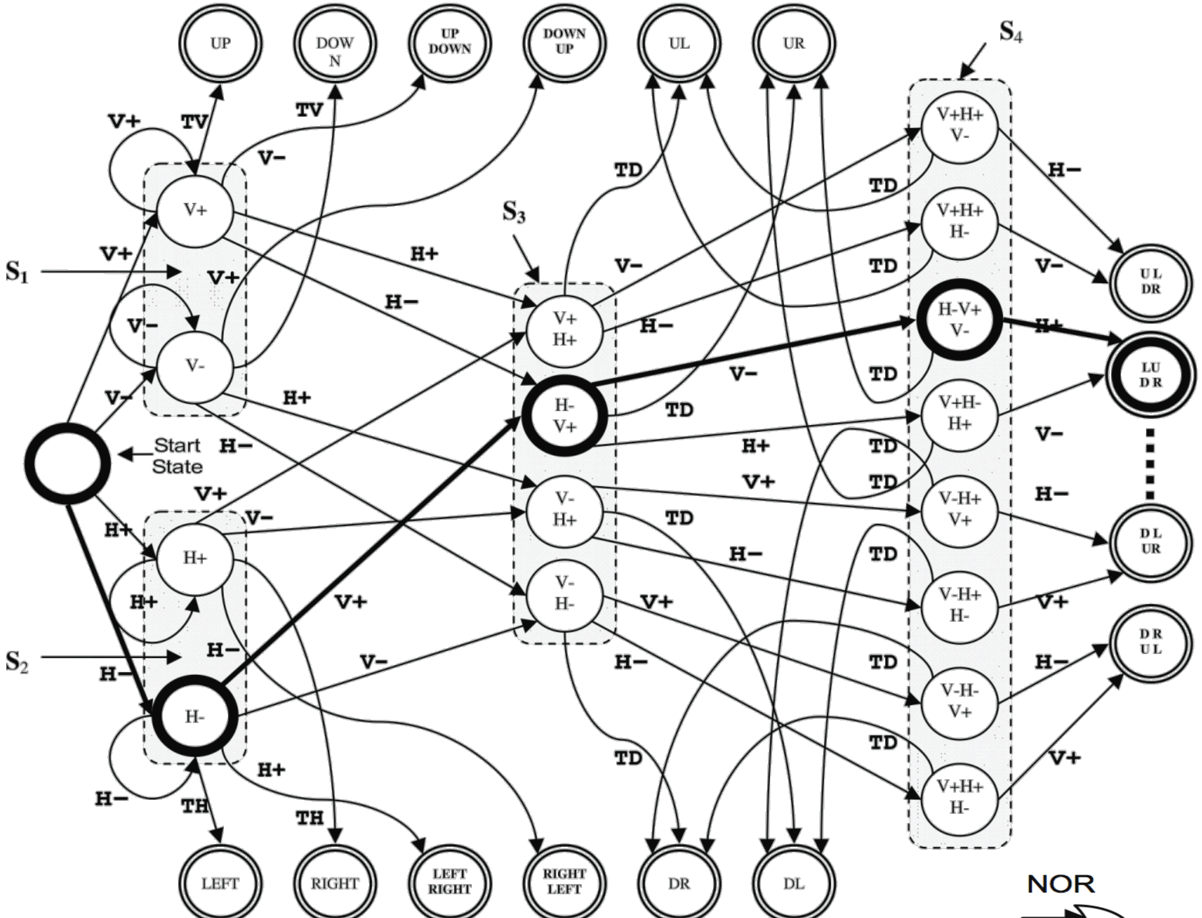
Touch Pad

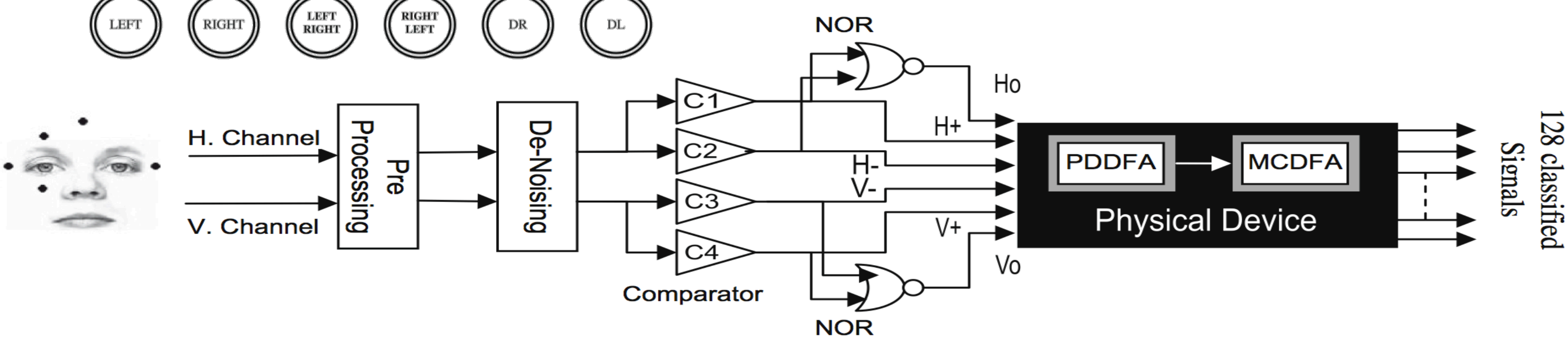
EOG based Integrated Assistive Device





MODEL for Control Signal Generation





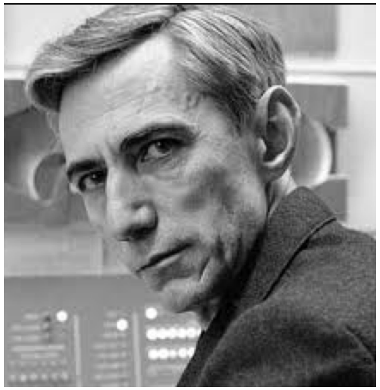
Nature of Information in the Brain

- Plasticity and learning play an important role in rehabilitation

- What's the nature of information encoding in the brain?

  - Efficient Information encoding
  - Multimodal Information Linkage

Principle of efficient encoding



Claude Shannon *(1916-2001)*. Shannon's seminal 1948 paper, "A Mathematical Theory of Communication," established a whole new discipline, Information Theory!

- Minimize redundancy and increase efficiency

Horace Barlow in 1961 as a theoretical model of sensory coding in the brain (efficient coding hypothesis)

Communication as well as encoding of information is most efficient, if there is reduction in redundancy.

Shannon's Concept of Redundancy

BARLOW, H. B., & FÖLDIÁK, P. (1989). Adaptation and decorrelation in the cortex. In R. Durbin, C. Miall, & G. Mitchison (Ed.), The Computing Neuron (pp. 54-72). Wokingham, England: Addison-Wesley.

4
Adaptation and Decorrelation in the Cortex

Horace Barlow & Peter Földiák

Summary

Any small region of the cortex receives input through a large number of afferent fibres, and transmits efferent output to other regions of the brain. If the units interact according to an anti-Hebbian rule, the outputs define a coordinate system in which there are no correlations even when the input fibres show strong correlations. The idea that cortex performs such decorrelation has several theoretical merits and fits some prominent facts about the cortex:

Shannon's concept of redundancy and it's insight into mechanisms of sensory processing, perception, intelligence and inference play an important role both in engineering and biology.

Does the human brain actually use this principle?

There is no direct evidence so far due to technical challenges like observing neural encoding in very initial stages of development.

Alternative:

Working with newly sighted children might present a way forward.

But,

The challenge lies in **“Critical Period”** hypothesis!

"Visual learning is subject to a critical period"

Riesen, Austin, H. 1950
Arrested Vision, Scientific American

Wiesel, T.N. and Hubel, D.H., 1965
Extent of recovery from the effects of visual deprivation in kittens, J. Neurophysiol.,

Van Hof-Van Duin, J., 1976
Development of visuo-motor behavior in normal and dark-reared cats, Brain Res., 104 233-241.

Timney, B., Mitchell, D. E. & Giffin, F. 1978
The development of vision in cats after extended periods of dark-rearing. Experimental Brain Research 31, 547-560.

Cynader, M. & Mitchell, D. E. 1980
Prolonged sensitivity to monocular deprivation in dark-reared cats. , Journal of Neurophysiology 43, 1026-1040.

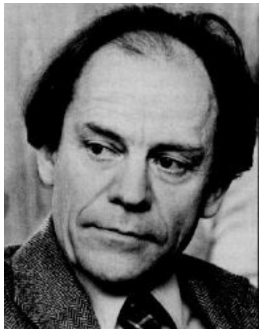
Smith, D.C., Lorber, R., Stanford, L.R. and Loop, M.S. 1980
Visual acuity following binocular deprivation in the cat, Brain Res., 183.

Mower, G. D., Caplan, C. J. and Letsou, G., 1982
Behavioral recovery from binocular deprivation in the cat, Behavioural Brain Research, 4

Kaye, M., Mitchell, D. E. & Cynader, M. 1982
Depth perception, eye alignment and cortical ocular dominance of dark-reared cats. Developmental Brain Research 2, 37-53.

Mitchell, D. E. 1988
The extent of visual recovery from early monocular or binocular visual deprivation in kittens, Journal of Physiology

David Hubel



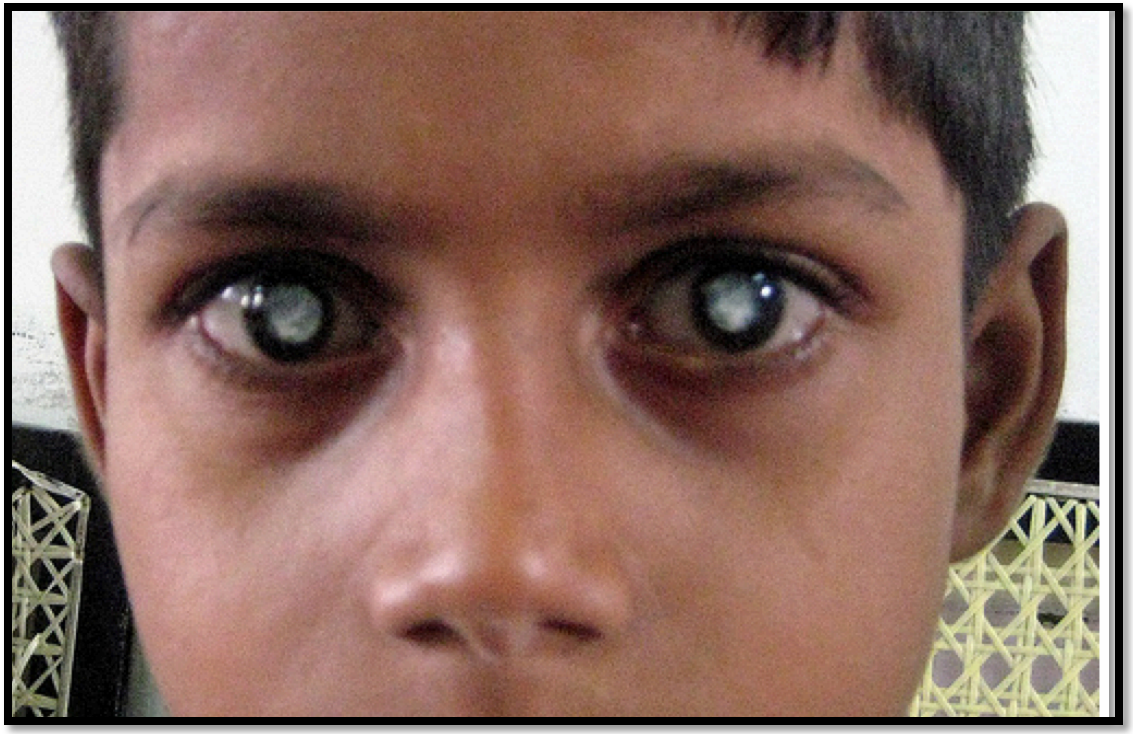
Torsten Wiesel

Nobel Prize, 1981

…and many more

But, all of these results come from animals. What about humans?

Will vision develop after surgery?



Two foundational questions:

1. Can the brain change late in life?

2. Is the change consistent with the theory of redundancy reduction?

Let's find out

Experimental Goal:

To determine if the brain of a newly sighted child changes in a manner consistent with the principle of redundancy reduction.

A positive result will accomplish two big objectives

1. Force a rethink of the critical period dogma
2. Show for the 1st time, usage of efficient information encoding principle by human brain

Brain: Is the brain 'plastic' enough to make use of information from the eyes later on in life?

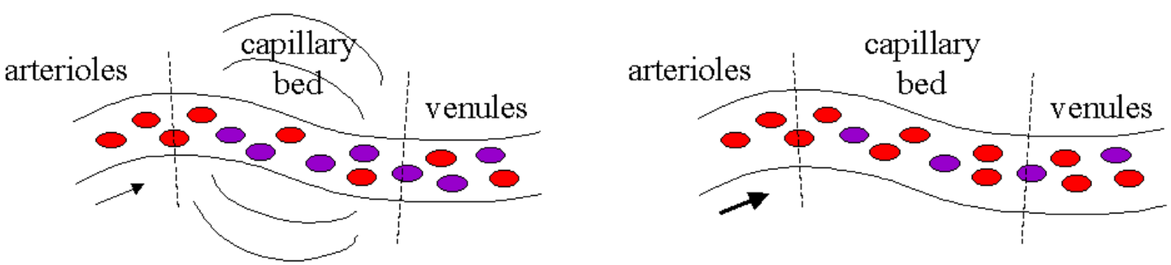
Behavior: Can a child, blind for several years since birth, benefit from optical correction of the eye?

BOLD-contrast Imaging

Blood Oxygen Level Dependent signal

↑neural activity ➔ ↑ blood flow ➔ ↑ oxyhemoglobin ➔ ↑ T2* ➔ ↑ MR signal

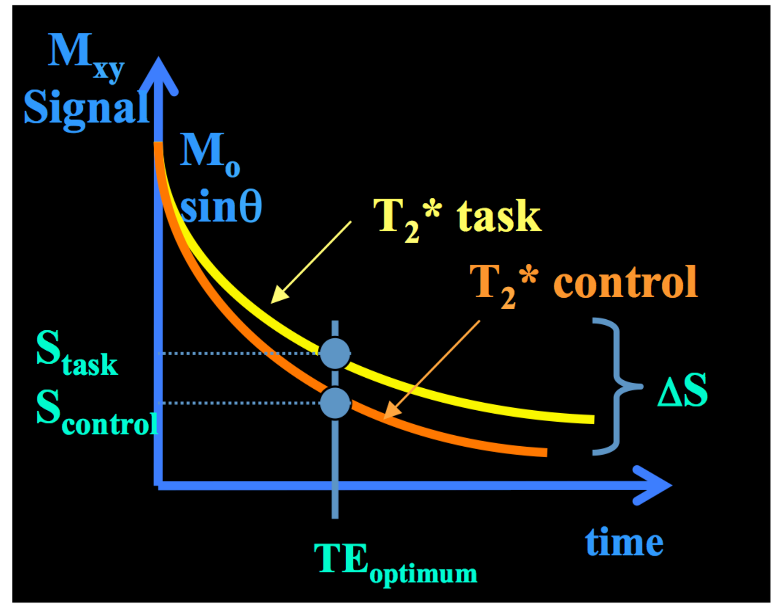
<u>Basal state</u> <u>Activated state</u>



- normal flow
- basal level [Hbr]
- basal CBV
- normal MRI signal

(red) = HbO_2
(purple) = Hbr

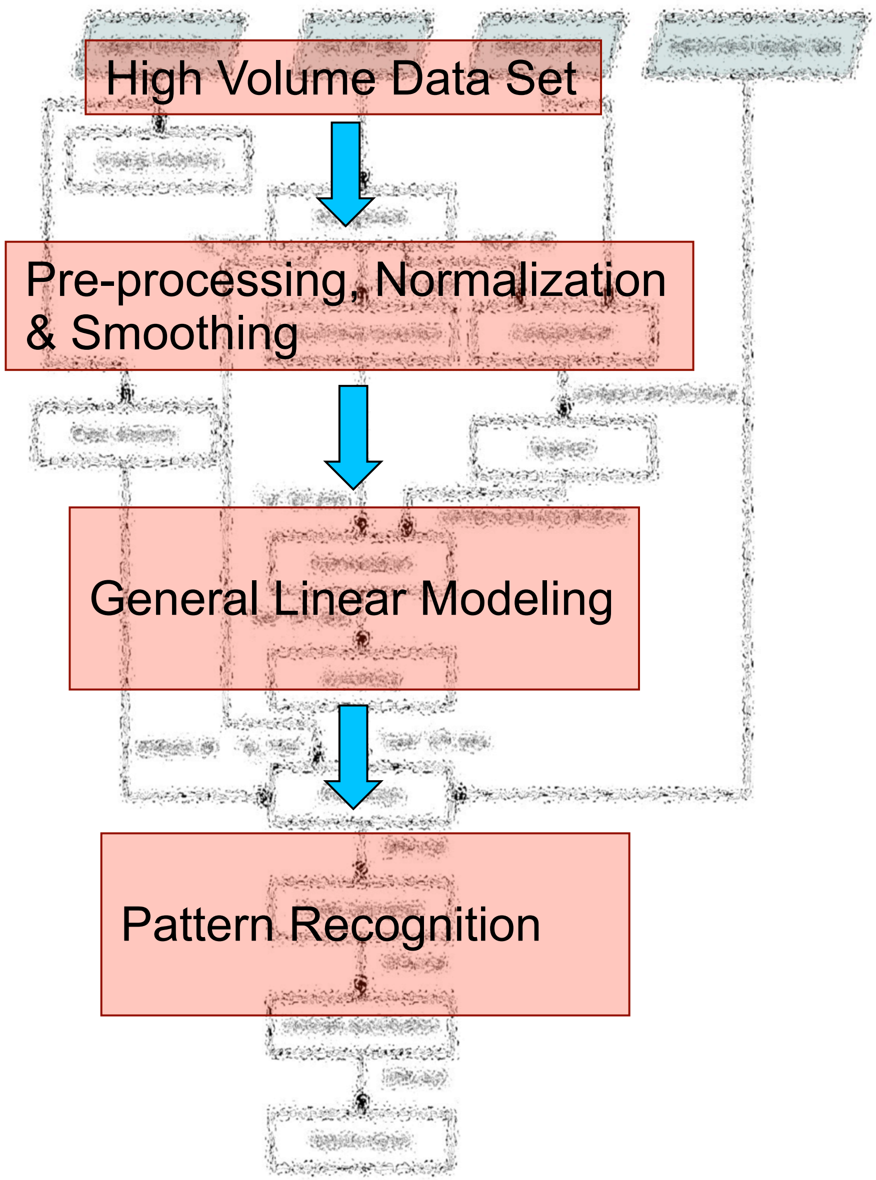
- increased flow
- decreased [Hbr] (*lower field gradients around vessels*)
- increased CBV
- increased MRI signal (*from lower field gradients*)

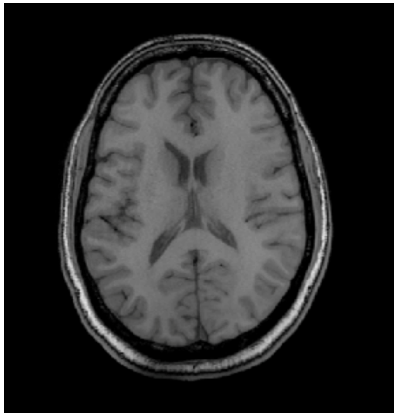


Source: [fMRIB Brief Introduction to fMRI]

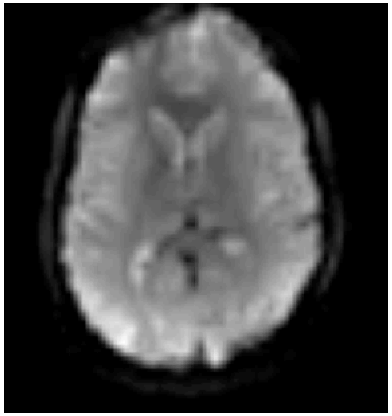
Source: Jorge Jovicich

Flow Chart: Processing Images

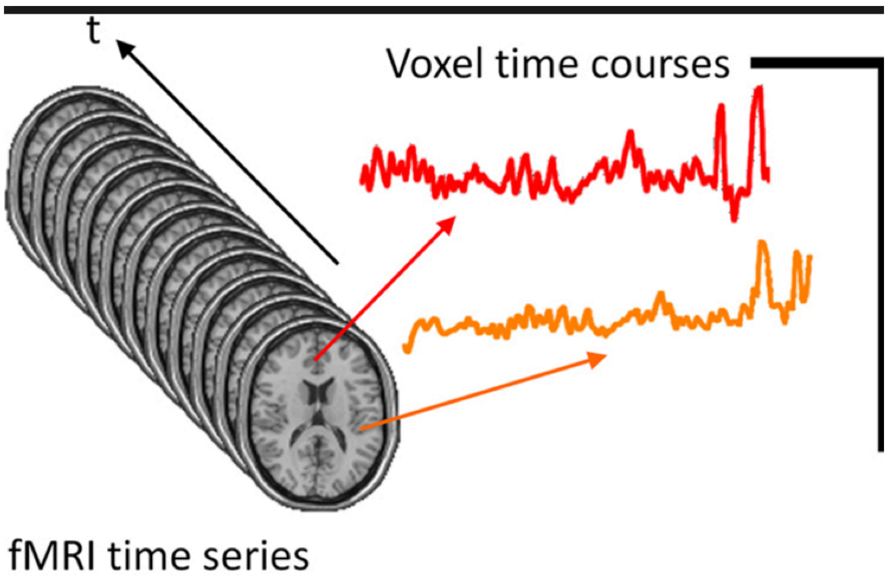




Structural Image



Functional Image



Resting State Functional Connectivity

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

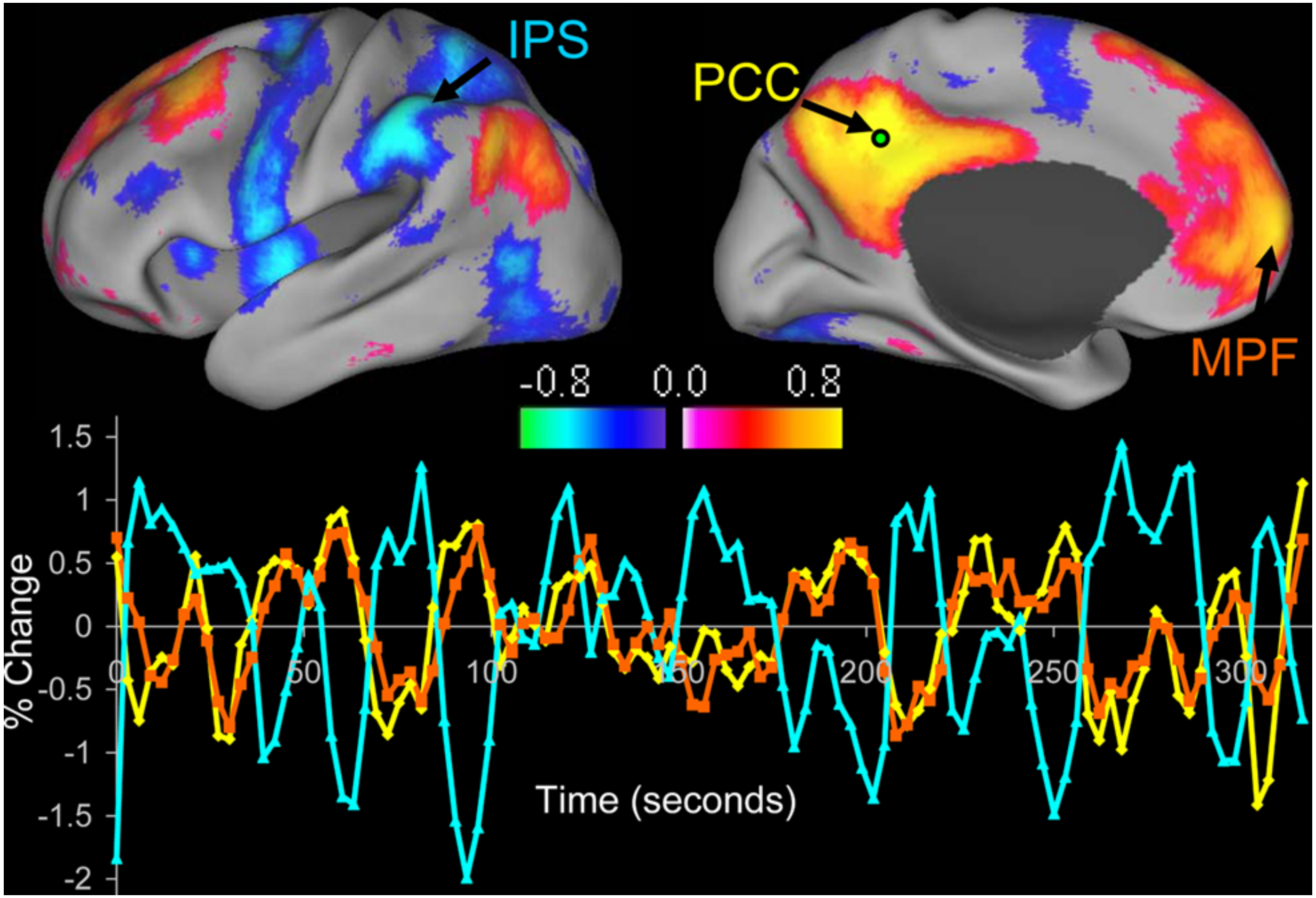
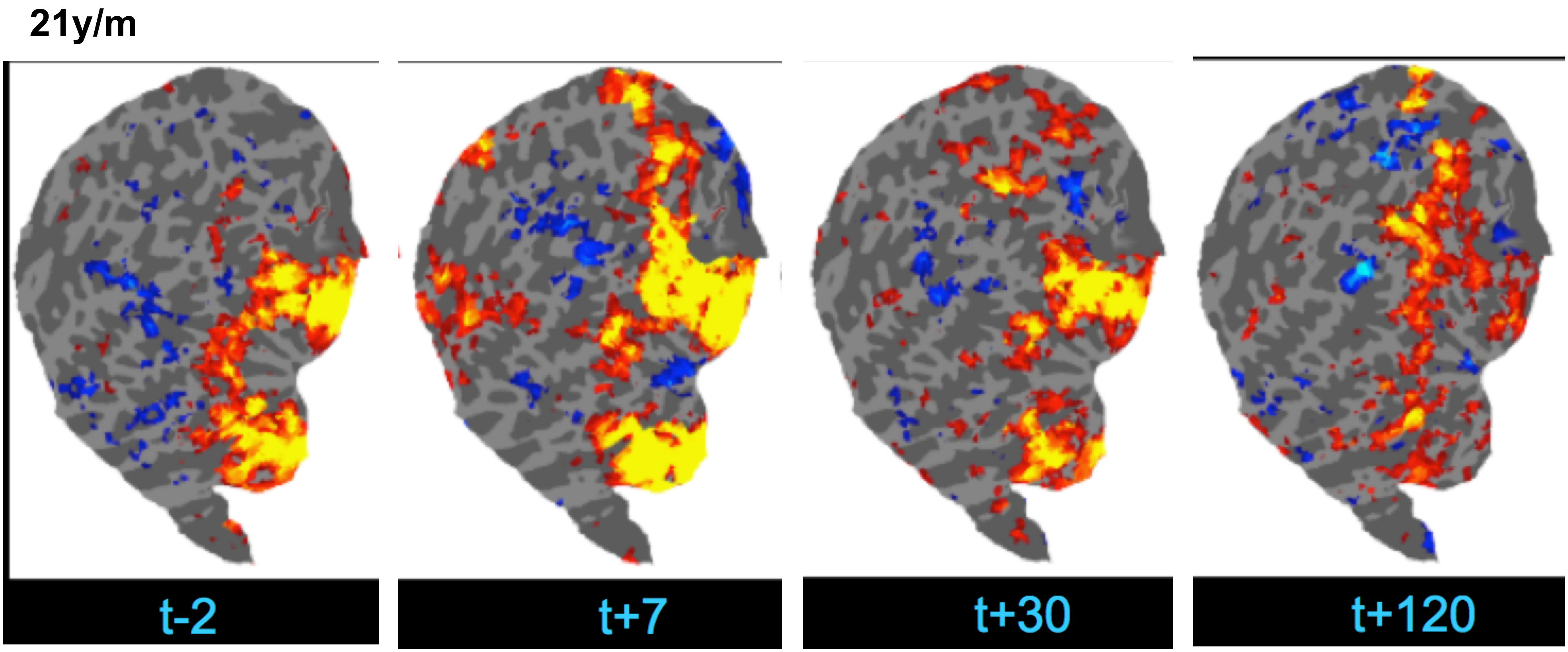
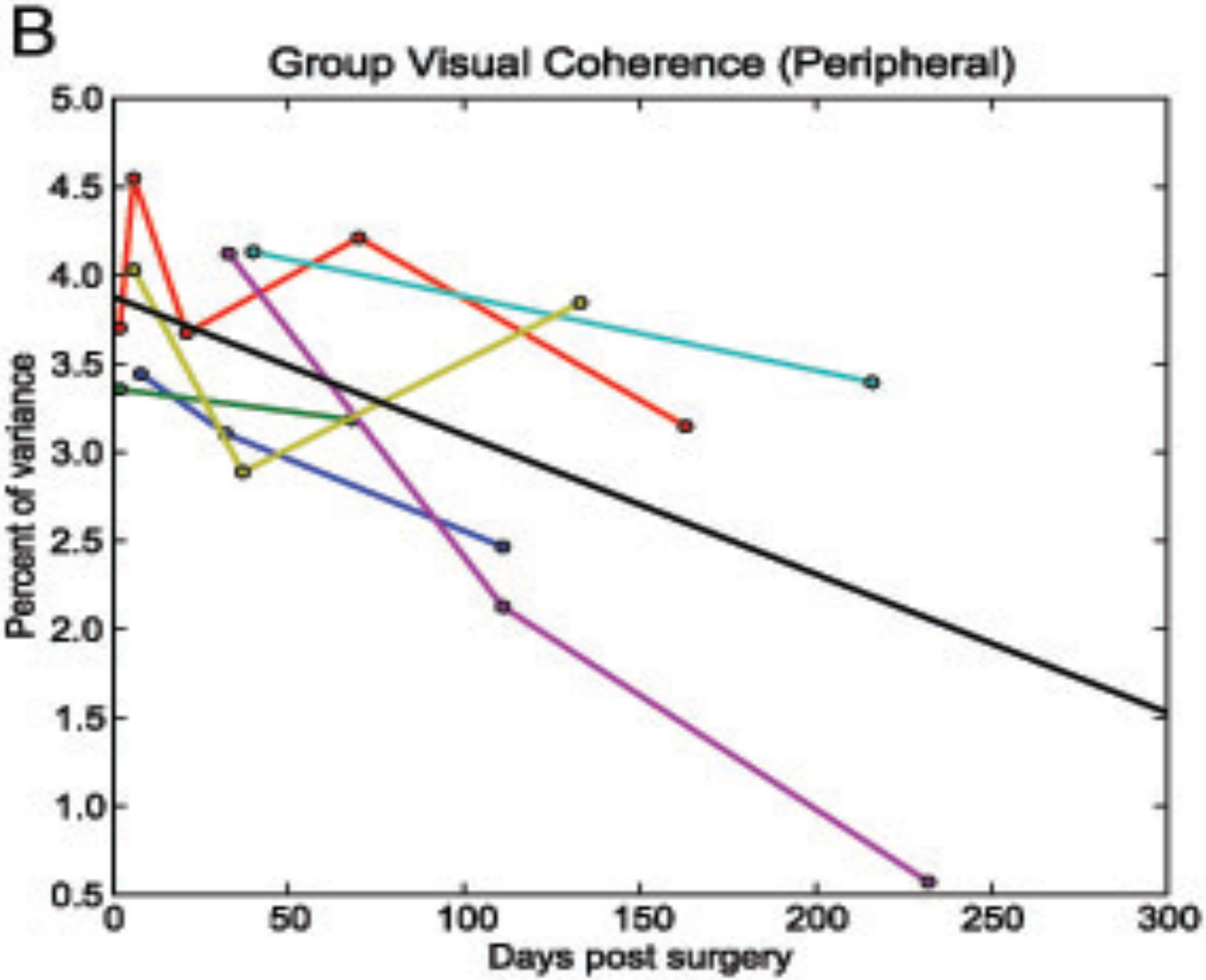


Image courtesy: Fox and Greicius (2010) Front. Syst. Neurosci.



Progressive cortical de-correlation following sight onset (After surgery)


B
Group Visual Coherence (Peripheral)
Percent of variance
Days post surgery
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
50
100
150
200
250
300

Brain: Is the brain 'plastic' enough to make use of information from the eyes later on in life? **YES**

Behavior: Can a child, blind for several years since birth, benefit from optical correction of the eye?

British Journal of Ophthalmology

Visual acuity outcomes after late treatment of bilateral congenital cataracts

Suma Ganesh, Priyanka Arora, Tapan Gandhi, Amy Kalia, Garga Chatterjee, Pawan Sinha

PNAS

Development of pattern vision following early and extended blindness

Amy Kalia[a,1,2], Luis Andres Lesmes[b,c,1], Michael Dorr[b], Tapan Gandhi[a,d], Garga Chatterjee[a], Suma Ganesh[e], Peter J. Bex[b], and Pawan Sinha[a]

Psychological SCIENCE
A Journal of the Association for Psychological Science

aps ASSOCIATION FOR PSYCHOLOGICAL SCIENCE

Improvement in Spatial Imagery Following Sight Onset Late in Childhood

Tapan K. Gandhi[1,2], Suma Ganesh[3], and Pawan Sinha[1]

Brain: Is the brain ‘plastic’ enough to make use of information from the eyes later on in life? YES

Behavior: Can a child, blind for several years since birth, benefit from optical correction of the eye? **YES**

Efficient encoding and redundancy reduction

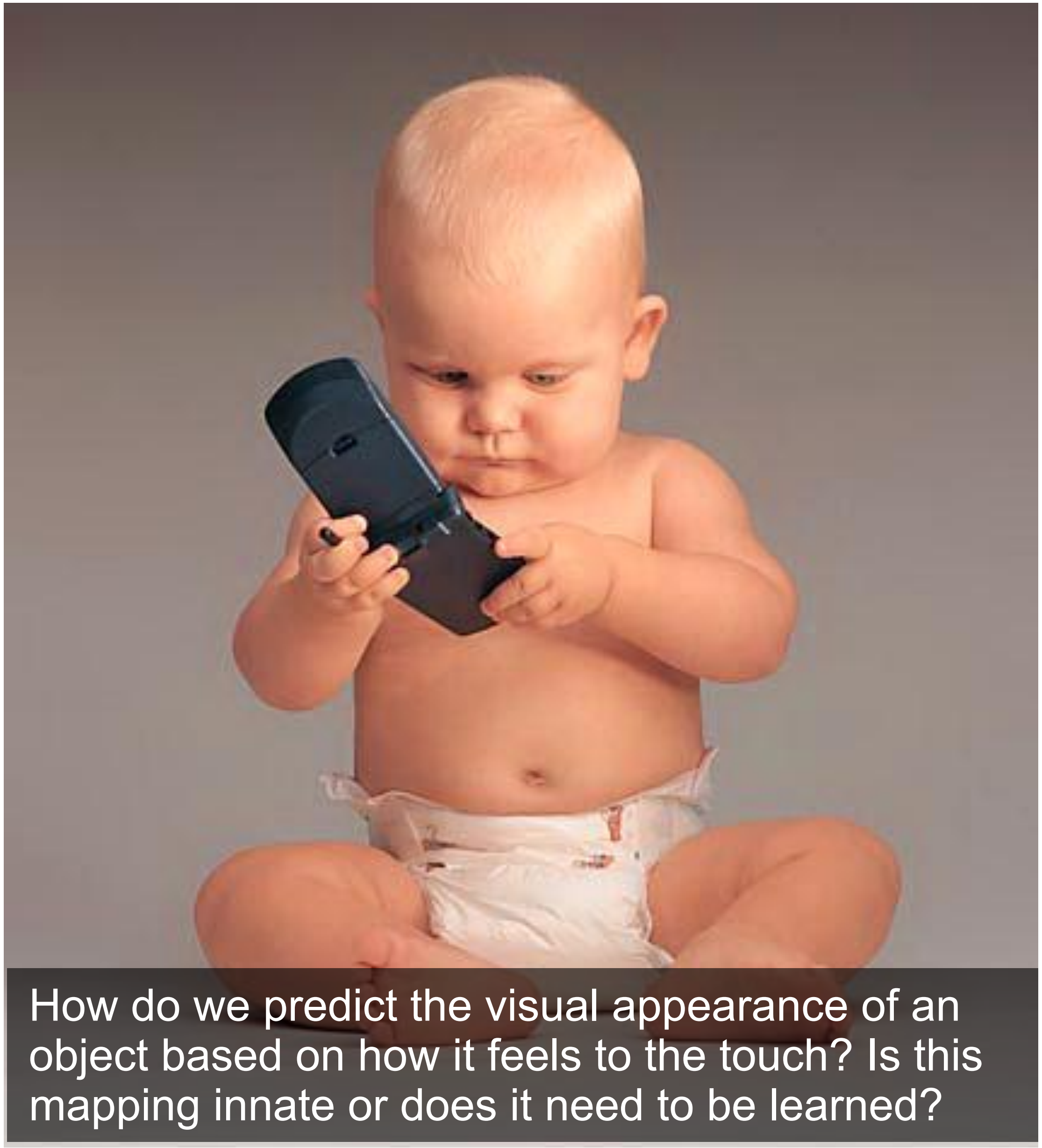
Efficient Information encoding

Multimodal Information Linkage

Besides giving us evidence that the brain can change, our results have also yielded clues about the development of important perceptual abilities and how they can be modeled in machine based systems.

A model for autonomous engineering inspired by human experimental data

Integrating information across the senses



How do we predict the visual appearance of an object based on how it feels to the touch? Is this mapping innate or does it need to be learned?

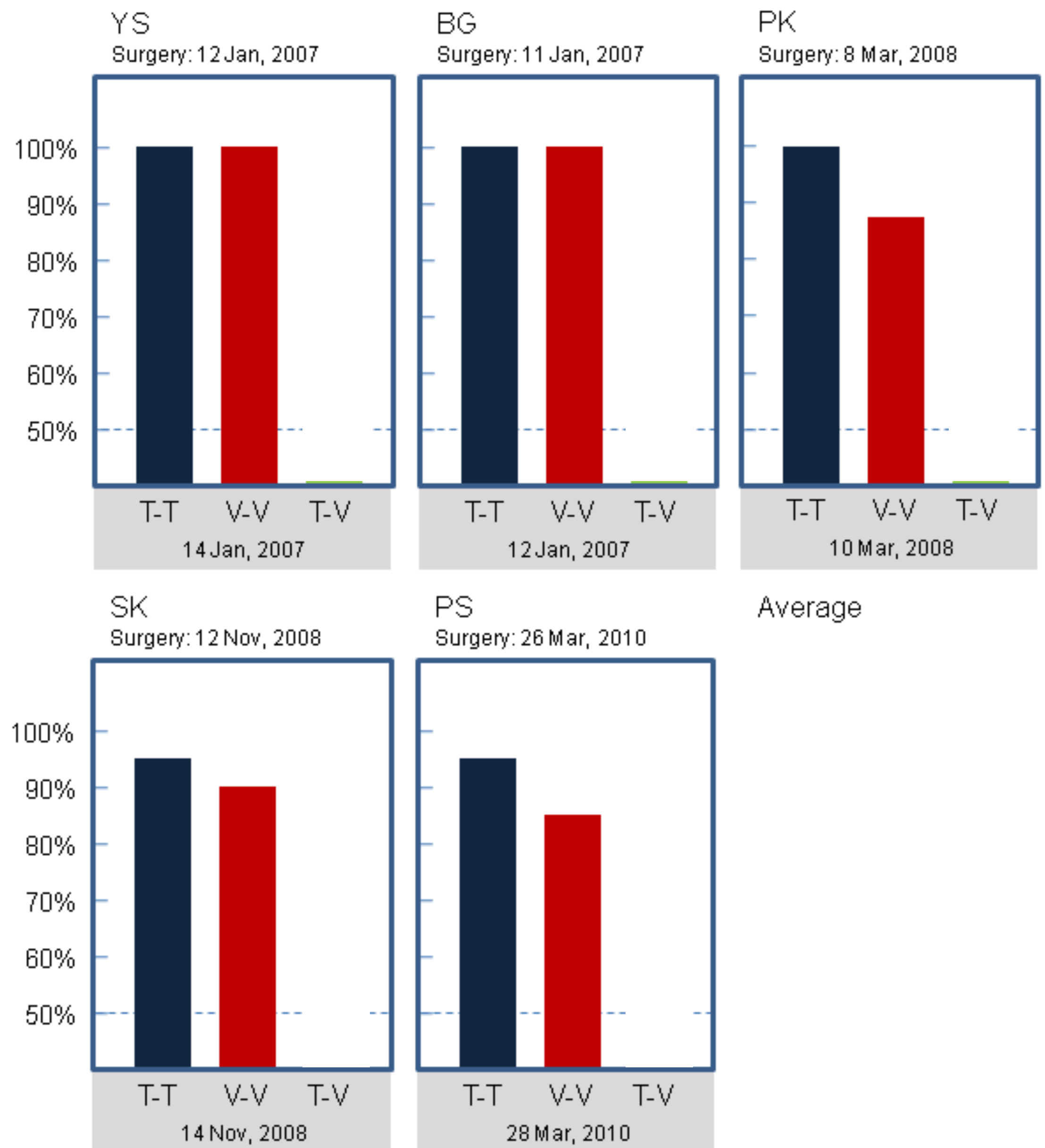
Molyneux's Problem

Suppose a man born blind, … and taught by his touch to distinguish between a cube and a sphere. Suppose the blind man be made to see: query, whether by his sight, before he touched them he could now distinguish and tell which is the sphere, which the cube?

-from Molyneux's letter to Locke (7 July, 1688)

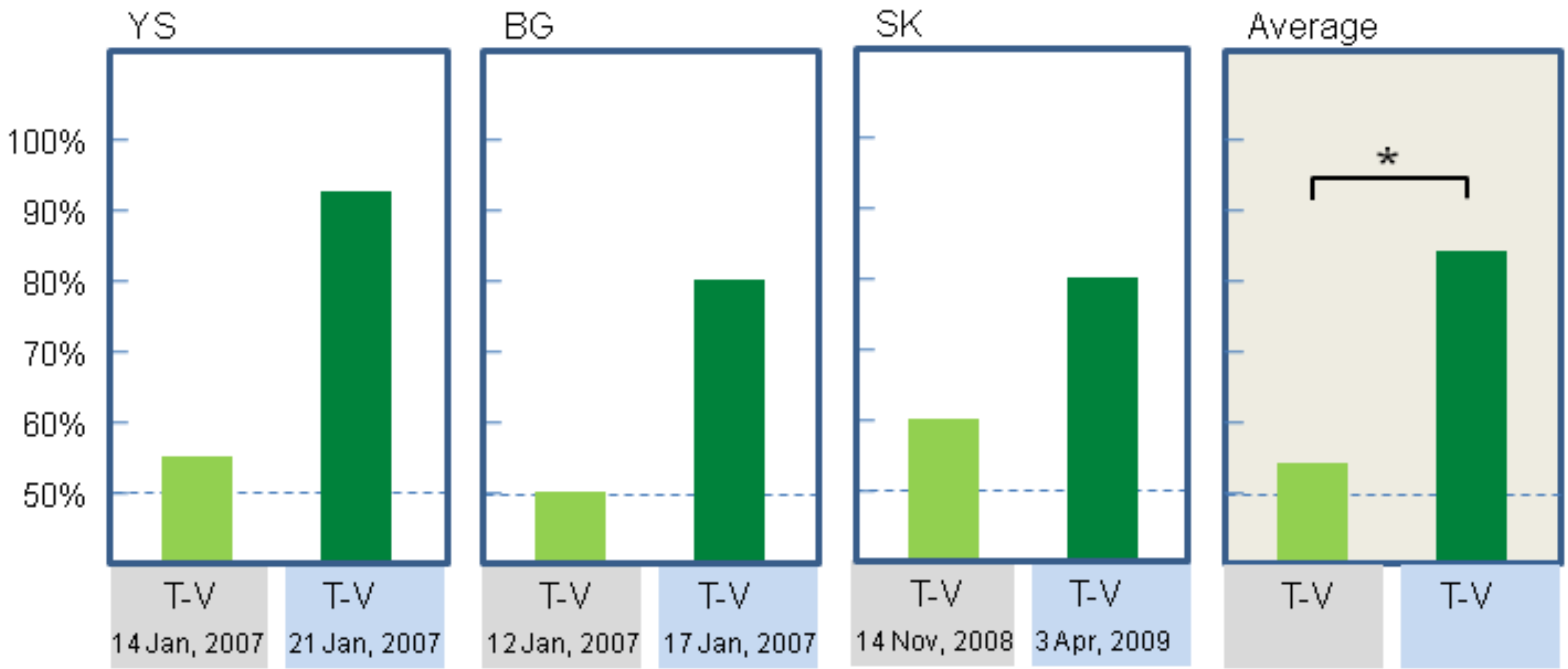
Stanford Encyclopedia of Philosophy: *There is no problem in the history of the philosophy of perception that has provoked more thought than the problem that Molyneux raised in 1688*

Experimental design diagram


YS
Surgery: 12 Jan, 2007
14 Jan, 2007
BG
Surgery: 11 Jan, 2007
12 Jan, 2007
PK
Surgery: 8 Mar, 2008
10 Mar, 2008
SK
Surgery: 12 Nov, 2008
14 Nov, 2008
PS
Surgery: 26 Mar, 2010
28 Mar, 2010
Average
100%
90%
80%
70%
60%
50%
T-T
V-V
T-V

Based on the results from the five subjects we have studied, it appears that **Molyneux's query is likely to have a negative answer**; the newly sighted show little transfer from touch to vision immediately after sight onset.

Besides this basic result, there is an interesting trend in the data…



Summary

There does not appear to be an immediate transfer from touch to vision after sight onset.

But, the ability to transfer is acquired rapidly.

Open question

What kinds of mechanisms might account for such rapid learning?

Currently we are trying to come up with a model to best describe the cross modal mapping and it's application in Engineering Design.

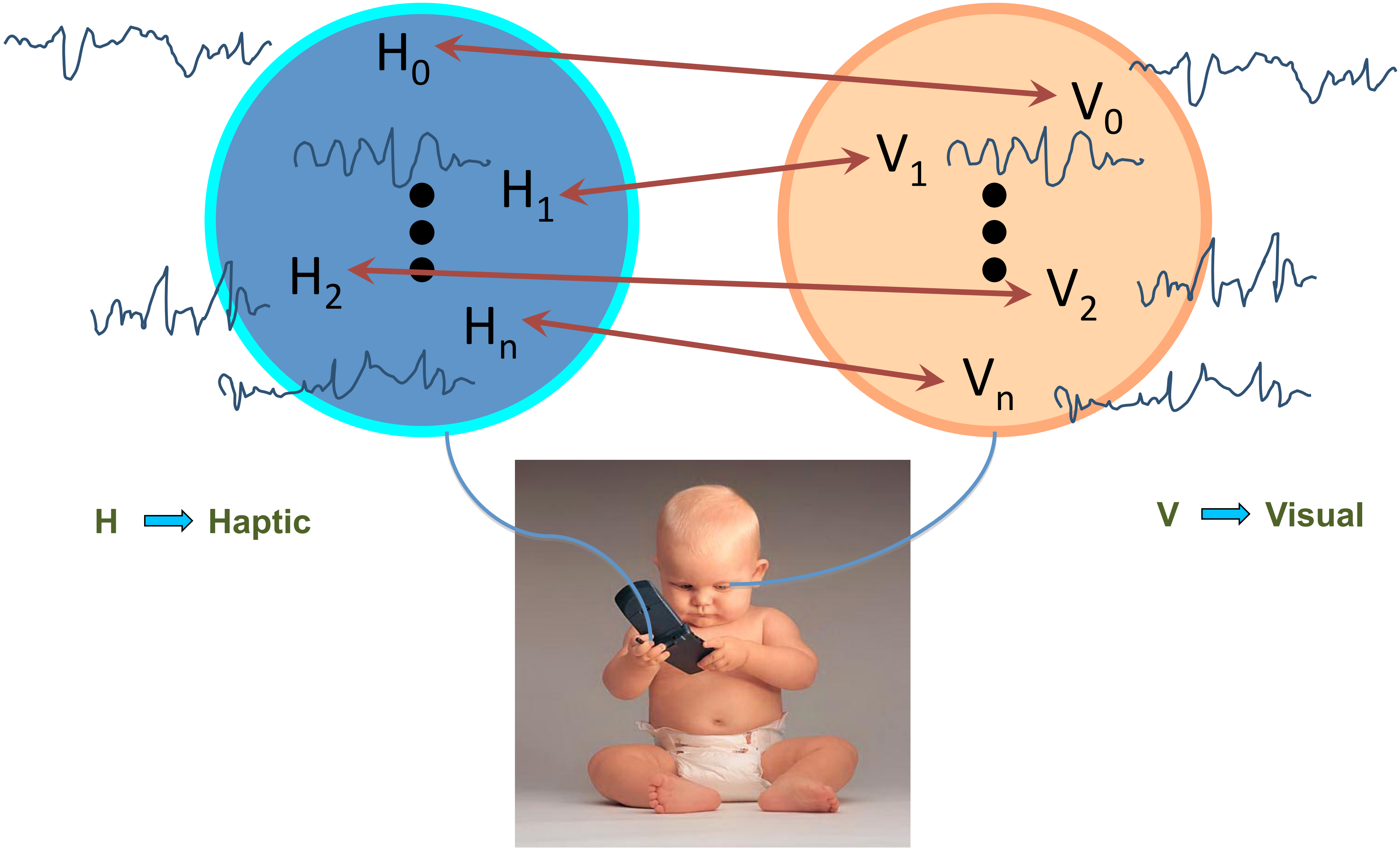
Nature Neuroscience (2011)

Maluma

Takiti

Haptic and Audio Interaction Design
Lecture Notes in Computer Science Volume 7989, 2013, pp 60-68.

How is the haptic to visual mapping acquired after gaining sight?

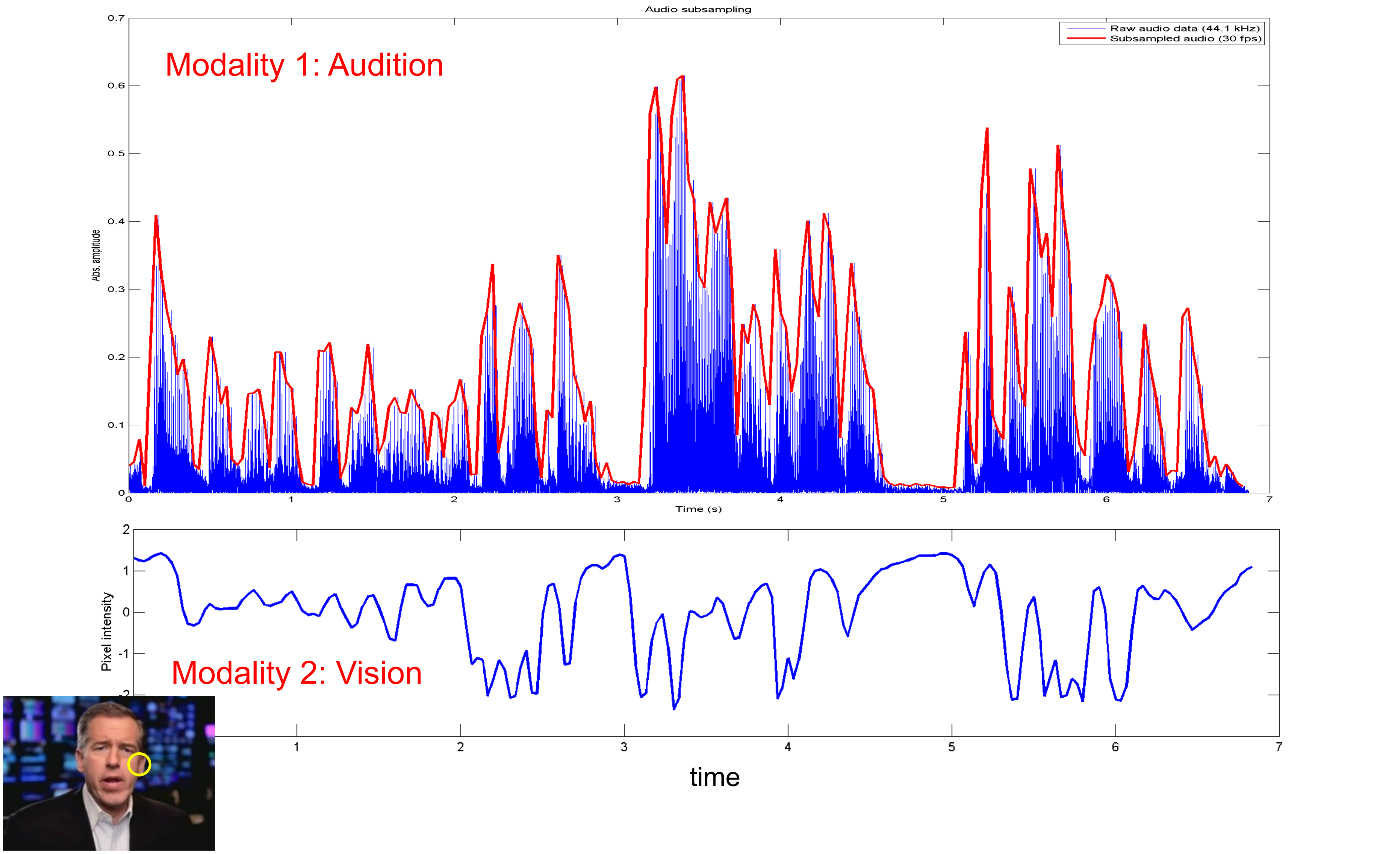


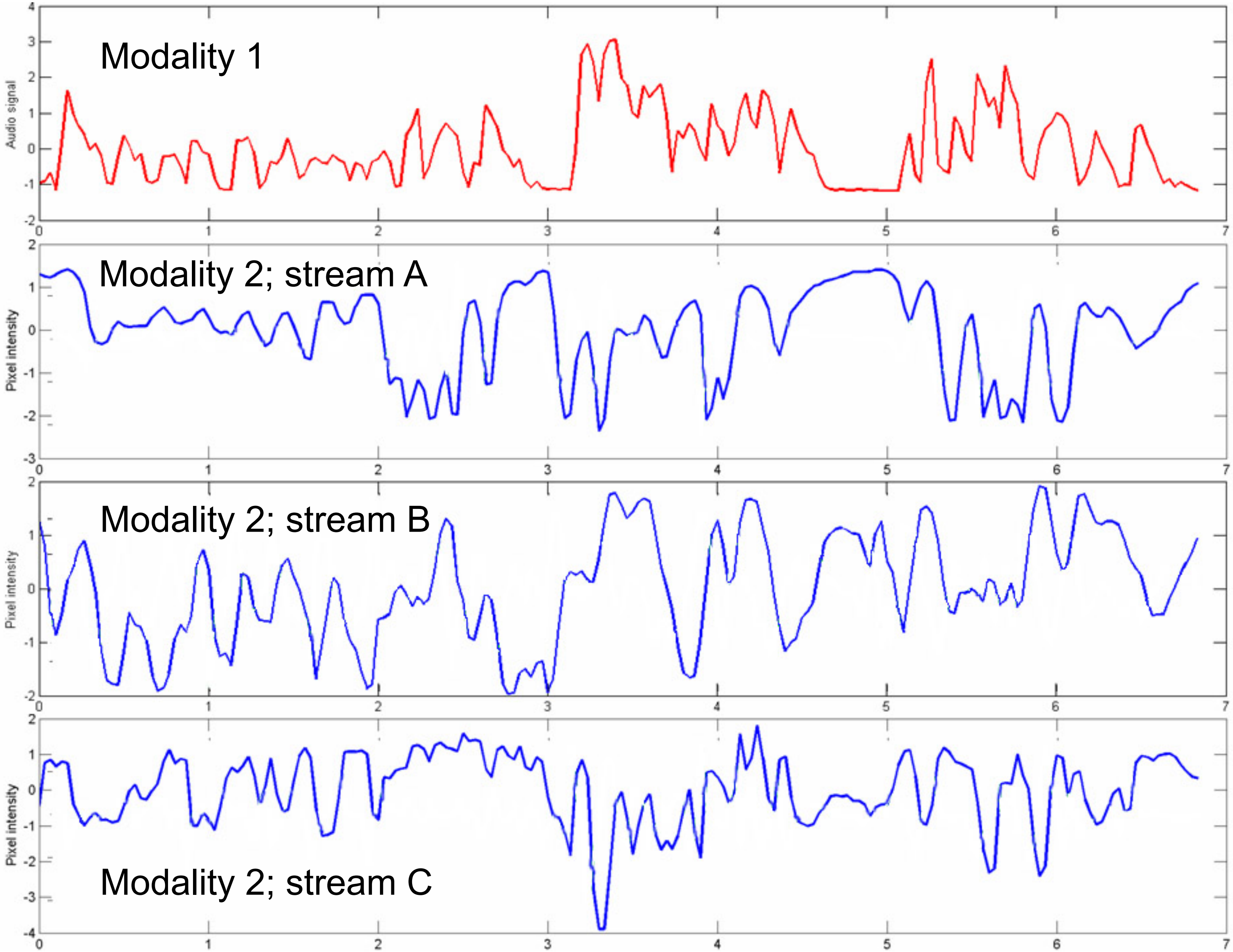
H ⟹ **Haptic**

V ⟹ **Visual**

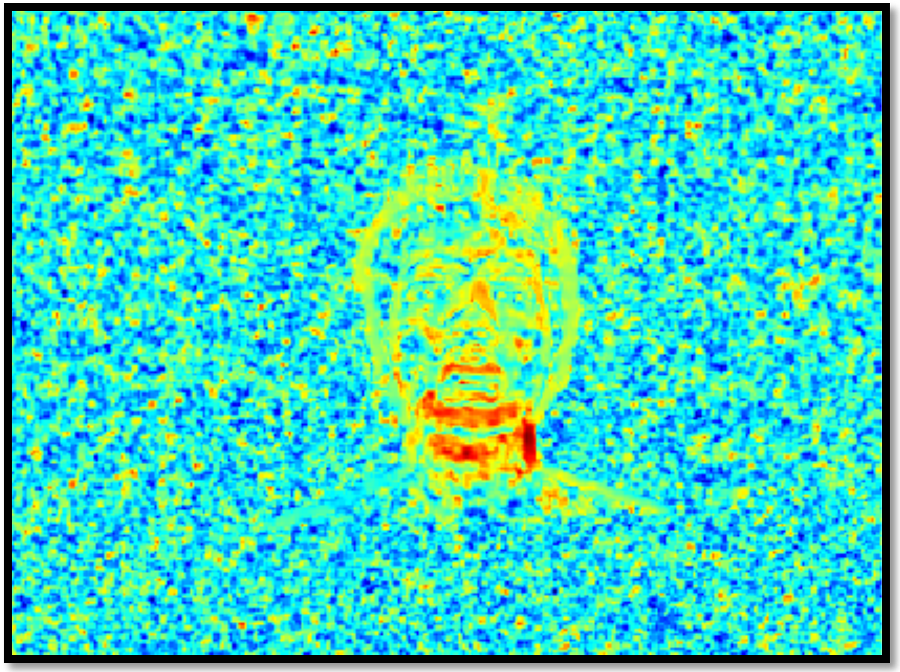
Audio-Visual Mapping

Detecting synchronies for inter-modal integration





Modality 1
Audio signal
Modality 2; stream A
Pixel intensity
Modality 2; stream B
Pixel intensity
Modality 2; stream C
Pixel intensity



A precursor to learning cross-modal mappings

Mouth configuration 1 ⟷ sound 1
Mouth configuration 2 ⟷ sound 2

Generalization: Mouth configuration n ⟷ ???

How is cross-modal mapping established?

The dynamics of the environment may play a key role.

Summary

- Evidence of cortical changes demonstrating
  - Plasticity well after putative critical periods
  - Usage of principle of efficient encoding in the brain

- Evidence of learnability of cross-modal linkages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AAAS
Seeing the light
Restoring sight in Indian children illuminates the brain p. 372

The New York Times

The New York Times

TUESDAY, APRIL 26, 2011

Study of Vision Tackles a Philosophy Riddle

By NICHOLAS BAKALAR

If a blind person were suddenly able to see, would he be able to recognize by sight the shape of an object he previously knew only by touch? Presented with a cube and a globe, could he tell which was which just by looking?

Pause for a moment and think of the answer. Then read on.

The question goes to the heart of a problem in the philosophy of mind: Is there an innate conception of space common to both sight and touch, or do we learn that relationship only through experience? Research published online April 10 in the journal Nature Neuroscience may have finally answered the question, which has vexed philosophers and scientists for more than 300 years.

William Molyneux, an Irish politician and scientist, first raised the issue in a letter to John Locke in 1688. Locke took up what came to be known as Molyneux's problem in "An Essay Concerning Human Understanding," published a few years later.

Locke's answer was no. "He would not be able with certainty to say which was the globe, which the cube, whilst he only saw them," he wrote, "though he could unerringly name them by his touch." For Locke, the connection between the senses was learned.

Dozens of philosophers have since considered the problem, among them George Berkeley, Gottfried Leibniz, Voltaire, Diderot, Adam Smith and William James. And some efforts have been made to answer the question experimentally, beginning in the early 18th century with studies of patients whose congenital cataracts had been removed in adulthood and continuing recently in observations of newborns.

NATIONAL PORTRAIT GALLERY

NAMESAKE William Molyneux wondered in the 1600s whether sight and touch are mere extensions of a single innate sense.

But according to the authors of the new experiment, the studies have been inadequate, never establishing how well the patient could see afterward, or failing to test soon enough after surgery so that the subject was still completely inexperienced with vision.

The new research appears to show definitively that Locke was right. The brain cannot immediately make sense of what the eyes are taking in, and the blind man given the ability to see cannot distinguish the two objects. But he can very quickly learn to do so.

Working with a group that provides medical treatment to the blind and visually impaired in resource-poor countries, the researchers tested five subjects from rural northern India, four boys and a girl ages 8 to 17. A all had been blind since birth, one with a disorder of the cornea, and the others with cataracts. Before their operations they could perceive light, and two could discern its direction, but none could see objects. Afterward, they all had vision measured at 20/160 or better, good enough to distinguish objects and carry out the tasks of daily living.

The children were tested within 48 hours of their operations. The researchers placed 20 small objects similar to Lego blocks on a table where they could be seen, but not touched. Then they had the children feel identical blocks under the table where they were invisible, and try to match them with those they could see. The average performance in matching one object with another by either touch or sight alone was high, close to 100 percent. Yet when they were asked to match an object they had felt with an object seen, the average number of correct answers dropped to barely better than chance.

But improvement was rapid. A co-author of the study, Yuri Ostrovsky, a postdoctoral fellow at M.I.T., said one child was proficient in less than a week. Within three months, the average number of right answers in matching an object seen with one touched was above 80 percent.

The lead author, Pawan Sinha, a professor of vision and computational neuroscience at M.I.T., believes that answering the philosophical question is not the only benefit.

"This paper strengthens the case that cross-modal learning is possible despite years of deprivation," Dr. Sinha said. "That's very important from a clinical perspective because it argues for making a treatment available to all, irrespective of age. Children beyond 6 or 7 are not beyond the correctable age. The brain retains its plasticity well into late childhood and even into adulthood."

Nature

NATURE|Vol 441|18 May 2006

LOOK AND LEARN

Prevailing wisdom says the adult brain cannot learn to see if it had no visual stimulation during childhood, but blind people in India seem to be breaking all the rules. Apoorva Man... reports.

Doctors gave SK his first pair of glasses in July 2004. He had been too poor to afford a pair before — but ... a 29-year-old blind ... Had he

tradict Wiesel and ... glasses, his visual ac... than the standard ... even the World H... tion of legal blin... with aphakia, SK... ment, which arg... to develop nor... With his

gration — the process that allows SK to resolve separate objects into a cow — might take even

SK's case has led Sinha to some interesting tangents. For example, children with autism

A. MANDAVILLI

Staff at Dr Shroff's Charitable Eye Hospital are trying to reduce the levels of blindness in India.

brains of children and ... restored later in life. He ... of the visual cortex in th... ulated by light. Sinha ... how much of the cortex ... other functions such a... whether this change is ... is a very, very fundam...

Presumably, the chi... different skills to vary... mation might help d... tion programmes and ... visual abilities com... which develop over ... the evidence is con... that the brain is mu... suspected," says Ka... should tell us to go ...

Apoorva Mandavill...
Nature Medicine.

1. Polat, U., Ma-Naim, T. ... Sci. USA 101, 6692–6...
2. Fine, I. et al. Nature N...
3. Bertone, A., Mottron ... Neurosci. 15, 218–22...
4. Blake, R., Turner, L. ... Stone, W. L. Psychol...

nature International weekly journal of science

Children born blind can learn to see as teenagers

The brain adapts to surgery to correct congenital cataract in children as old as 15.

Madhusree Mukerjee

29 January 2014

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Pawan Sinha

By displaying images on an iPad, researchers tested patients' ability to detect contrast after their vision was restored by cataract surgery.

TIME

By CAROLYN SAYRE

NEUROSCIENTISTS HAVE long been convinced that the first few years of life are a crucial period for brain development—a time when connections between neurons are being forged at a prodigious rate as a baby learns to make sense of the external world. Interfere with that process, and you can cause permanent, irrevocable damage. If a child is born blind, for example, it's pretty much over by age 6. You can fix the eyes, and they might be able to perceive light and dark. Without the right visual circuitry in place, though, there's no way to form images—the essence of true sight.

But then there's the patient known as S.R.D. Discovered by researchers four years ago in Ahmedabad, India, she was a 32-year-old, dirt-poor maid who had been born with severe cataracts. They were removed surgically when she was 12—and within a year, despite what neuroscientific dogma would have predicted, S.R.D. learned to see. Her case, described in the December issue of *Psychological Science*, is forcing scientists to rethink their long-held beliefs about vision. "There is a critical period for perfect acuity," says Pawan Sinha, associate professor of neuroscience at M.I.T. and a co-author of the paper. "But there is not a critical period for learning to do complex visual tasks."

This surprising insight had its genesis in

An Unlikely Vision

Defying scientific dogma, blind kids in India are learning to see

recognize her family's faces and identify objects. And that's a very big deal. Dr. Suma Ganesh, a pediatric ophthalmologist at the Dr. Shroff's Charity Eye Hospital in Old Delhi, India, used to believe that operating on blind children past the critical period was hopeless. But Project Prakash showed her that just isn't the case. "Even if a blind kid, after an operation, manages to see up to three meters, it makes a big difference," Ganesh says.

Important as the project has been to neuroscience, says Yuri Ostrovsky, a graduate student at M.I.T. and lead author of the paper, "the best thing about it is the humanitarian aspect." Project Prakash has funded about half a dozen mobile eye camps—teams of ophthalmologists that travel to remote areas of the country and provide eye care. The concept itself isn't new, but unlike other camps, these are aimed just at children.

Still, the science is remarkable. Since hearing S.R.D.'s story, the researchers have analyzed a total of 14 children and one adult at the eye hospital. All of them have shown significant improvement in less than a year. While most were treated surgically, the adult—a 29-year-old man with congenital aphakia (an eye missing its lens)—just needed a pair of glasses. Eighteen months later, he was able to see.

Although the results are undeniable, it's still unclear what's going on in the patients' brains. The researchers will start

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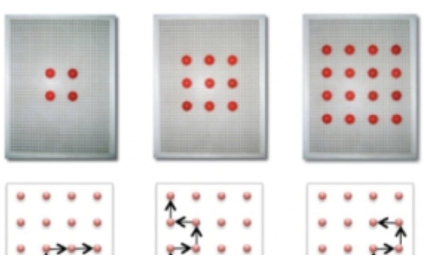

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"When they didn't have visual experience, they were still able to perform very simple tasks, but not very complex tasks. But when they received sight after the surgery, they developed this ability very fast," Gandhi says.

Researchers found that children who gained sight after early onset blindness had poor spatial resolution and contrast perception after cataract surgery (left panel depiction). Follow-up assessments revealed enhanced contrast sensitivity (middle panel). The artist of the painting (right panel) is a child who gained sight after

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