What do the eye and the hand tell us about the brain, and how this can be useful to people

Antonio Bicchi, Emiliano Ricciardi, Pietro Pietrini, Marco Santello
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The eye
A complex system
The hand
A Complex System

Proper digital arteries
Common digital artery
Superficial palmar arch
Deep palmar arch
Palmar carpal arch
Ulnar artery
Radial artery
A Complex System
Ligaments and Muscles

carpal radial long extensor

carpal radial short extensor

carpal ulnar extensor

finger extensor

Metacarpal bone

Collateral ligament

fingertip deep flexor (four tendons)
thumb long flexor (one tendon)

1st phalanx

2nd phalanx

3rd phalanx

tendons of interossei and lumbricals merge with tendons of finger extensor to constitute the extension system of the fingers

tendon of index extensor merges with a tendon of finger extensor

tendon of little finger extensor merges with a tendon of finger extensor

Collateral ligament
Tendons
Under a pin head
How can technology match the challenge of complexity to help people?
How can the brain cope?
Taming the Complexity

The Body:

- a cage for our mind
  or
- a dominating factor in determining how cognition has evolved in the admirable form we know?

Constraints that Define and Enable
Engineering and Neuroscience together: Understand to Build
Build to Understand
Compression and Abstraction

A large part of research on vision has focused on compression and on abstractions of visual data
• reduction of data for sensing, displaying, communicating
• extract information from an image
• extract information from sequences

Questions:
• how do we conceptualize what we see
• how do we close sensory-motor loops that imply decisions
• ... and how do we do it quickly!
An example: Optic Flow

Optic flow associates incremental changes in image with motion of objects relative to camera.

In human and artificial vision, optic flow crucial to fast sensory-motor feedback (e.g. time-to-contact).
An Optic Flow “processor” embedded in the brain

Continuously changing optic flow provides information about direction of heading and 3D structure of environment.

Functional MRI studies show area V5/MT of human cortex responds selectively to components of optic flow (circular, radial).

(Marrone et al., Nature 12/3, 2000)
Extensive neuroscientific evidence for the existence of sensorimotor synergies and constraints (Babinski, 1914!), Bernstein, Latash, Bizzi, Arbib, Jeannerod, Wolpert, Flanagan, Soechting, Sperry, …

- First two synergies explain ~84%, first three ~90% of the covariance.

First synergy alone more than 50%
To what extent is it possible to convey visual information through touch?

What are the mechanisms that underpin sensory substitution?
To what extent is it possible to convey visual information through touch?

What are the mechanisms that underpin sensory substitution?

- Crossmodality
- Supramodality
Lessons learned from the blind brain

Most of the research in blind individuals classically has focused on the compensatory plastic rearrangements that follow loss of sight, especially in ‘early visual’ areas (e.g. Braille reading).

Sadato et al., Nature, 1996
Lessons learned from the blind brain
Towards a more abstract representation…

- Functional brain studies in both sighted and congenitally blind individuals have shown the existence of supramodal brain regions able to process external information independently from the sensory modality through which such an information has been acquired.

- A more abstract nature of functional cortical organization may enable congenitally blind individuals to acquire knowledge, form mental representations of and interact effectively with an external world that they have never seen.

Ricciardi and Pietrini, Curr Opin Neurol, 2011
Ricciardi et al., Neurosci Biobehav Rev, 2013
Both visual and non-visual motion perception not only share fundamental psychophysical aspects, but also recruit a specific circuit within the middle temporal complex (hMT) in both sighted and congenitally blind individuals.
Coherent changes in **visual** images caused by object or viewer movement are called optic flow: it provides information about object form, position, orientation, and movement, as well as self-motion within the environment.

**Tactile** exploration of the environment involves analogous changes in tactile images, or ‘tactile flow’: it provides information about object form, position and movement, softness.
Supramodality for several perceptual and cognitive functions...

- Spatial orientation (Garg et al., 2007)
- Spatial localization (Vanierde et al., 2003; Gougeux et al., 2003; S hates et al., 2005; Boccia et al., 2008; Eilmeier et al., 2007; Collignon et al., 2010; Kupers et al., 2010).
- Tool use (Mahon et al., 2010).
- Voice perception (Gougeux et al., 2009).
- Object shape recognition (Pietrini et al., 2004; Mahon et al., 2009; Amedi et al., 2007, 2010; Tal et al., 2009).
- Motion perception (Ricciardi et al., 2007, 2010; Pourier et al., 2006; Matteau et al., 2010; Sani et al., 2010).

Similar cortical networks subsume visual and non-visual perception of form, tool, space and motion.
But also affective and social life: a supramodal mirror system for actions

- The human “mirror” system is thought to play a major role not only in action and intention understanding, but also in learning by imitation, empathy, and language development.
To what extent is vision really necessary for the human brain to develop and function?

New light from the dark
Is vision the only way "to see"?
Is vision the only way to see?
A supramodal mirror system for actions

- Blind individuals response to action sounds overlapped with the mirror system of sighted
- Visual experience is not necessary for the development of an efficient ‘social’ brain
To what extent is vision really necessary for the human brain to develop and function?
Which is the fate of unisensory visual brain areas in congenitally blind individuals?
Is task-specific the neural response in the deprived primary visual areas?
Which neural pathways may subserve the non-visual responses in the visual cortex of both sighted and congenitally blind individuals?

The Blind Brain Consortium (BBC) aims at answering these questions by gathering top research groups who work on blindness with behavioral, neuroimaging and molecular approaches.

Central to the mission of the BBC is facilitating and supporting biomedical research on visual deprivation, and ultimately improving the quality of life of blind individuals.

Research on the ‘blind brain’ has been undertaken by small groups from a wide range of different disciplines and mostly working independently of each other. The activities of the BBC should promote collaboration and data sharing across research groups and disciplines for better understanding of cortical development, cross-modal plasticity, supramodal organization, multisensory integration, and for progressing of sensory-substitution devices.
How Blindness can Open our Eyes on Brain Function
The Blind Brain Workshop - Pisa, October, 16-18th, 2013

- To what extent is vision really necessary for the human brain to develop and function?
- Which is the fate of unsensory visual brain areas in congenitally blind individuals?
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- Which neural pathways may subserve the non-visual responses in the visual cortex of both sighted and congenitally blind individuals?

The Blind Brain Workshop aims at answering these questions by gathering top researchers who work on blindness with neuroimaging and molecular methodologies to discuss about the state-of-the-art and future perspectives on what we can learn from studying the blind brain.

Cortical development, cross-modal plasticity, supramodal organization, multisensory integration, sensory-substitution devices are the major topics that will be covered and discussed in this two-days workshop.

Lectures will rely on speakers from different international laboratories and research groups providing their novel experimental findings and theoretical aspects on sensory deprivation in an informal environment offered by the summer spa residence of the Grand Duke of Tuscany.
Neural coding of motor synergies: recent data
Hands for Robots and Humans: Simple is Not Easy
The problem

How to make hands that are
– soft yet strong
– simple yet dextrous
– intelligent yet practical

Our Approach

- Soft Robotics Technology +
- Theory of Human Synergies =

Pisa-IIT SoftHand
Gray Ashtray
Innovative Design for Affordability and Robustness

Articular Joints and Soft Ligaments for Robustness & Safety
Innovative Design for Affordability and Robustness
The Pisa-IIT Soft Hand
One synergy, one motor
The Pisa-IIT Soft Hand Human Interface
The Pisa-IIT Soft Hand Human Interface
Wonders kids can do
Teleimpedance control of the Pisa/IIT SoftHand

Grasping different objects:

The stiffness and postural synergies are controlled by 2 channel EMGs for natural grasp.
Pisa-IIT SoftHand with Teleimpedance: Strong but Delicate
Grazie!

CENTRO “E. PIAGGIO”
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Grazie!