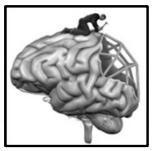
The Development of the Human Visual System and Neuroplasticity in Visual Impairment



Lotfi B. Merabet

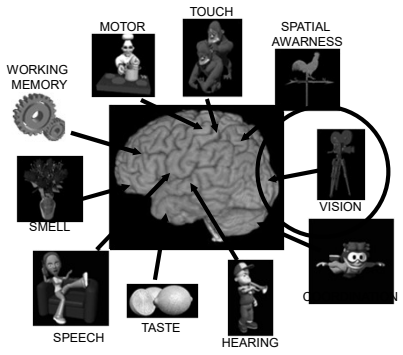
The Laboratory for Visual Neuroplasticity
Massachusetts Eye and Ear
Harvard Medical School

*No Financial Disclosures or Conflicts to Declare

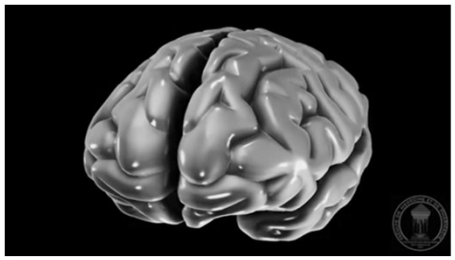
1

"neurology is like real estate"

2

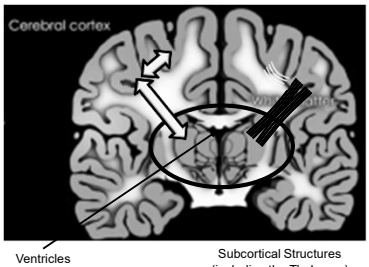


3



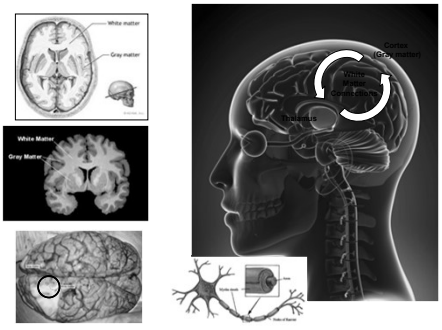
http://neuromatiq.net

4



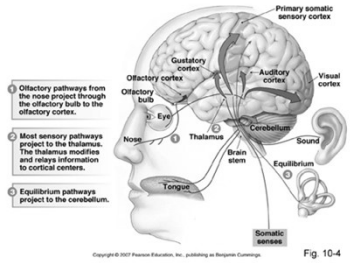
5

Gray Matter vs White Matter vs Subcortical



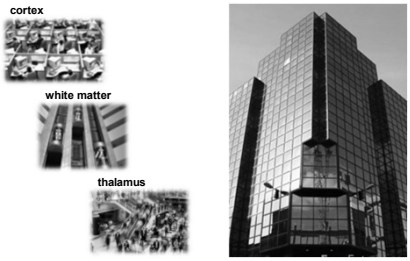
6

The Thalamus: The Subcortical Gateway to the Cortex



7

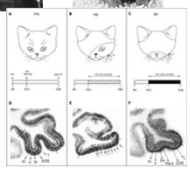
Gray Matter vs White Matter vs Subcortical: "The Building Analogy"



8

The Brain and Visual Development: The Role of Visual Experience

D. Hubel and T. Wiesel 1981



Critical (Sensitive) Period

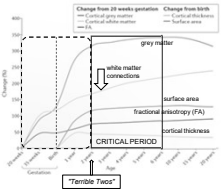
Stage during which the brain is especially sensitive to environmental stimuli and is crucial for brain development

(in humans, corresponds approximately between the ages of 2 and 7 years)

9

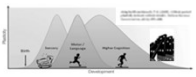
The Brain and Visual Development: The Importance of "Brain Wiring"

"The basic structural and functional framework of the brain is in place by the second year of life. Brain development after age 2 years is mainly reorganization, 'fine tuning', plasticity, and remodeling of established major circuits and networks."



Imaging Structural and Functional Brain Development in Early Childhood. Gilmore, Knickmeyer, Gao Nat Rev Neuro 2018

Simulations of vision as seen by a newborn and at various ages (courtesy Alex Wade)



"Windows of opportunity are also windows of potential vulnerability" T. Hensch

10

Life span stages	Infants			Young children			Older children			Teens			Young adults			Older adults	
Ages (years)	0 mo	3 mo	6 mo	1	2	4	5	8	11	12	16	20	21	35	50	55	68	80
Visual milestones																		
Binocular fusion		↑	→															
Stereopsis		↑	→															
Spatial acuity	↑	↑	↑	↑	↑	↑	↑	→									↓	↓
Contrast sensitivity	↑	↑	↑	↑	↑	↑	↑	→									↓	↓
Orientation	↑	↑	↑	↑	↑	↑	↑	→									↓	↓
Motion	↑	↑	↑	↑	↑	↑	↑	↑	↑	→							↓	↓
Color perception	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑								
Contour integration	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	→							
Face perception	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	→					↓	↓

The Development of Human Visual Cortex and Clinical Implications Siu and Murphy Eye and Brain 2018

11

to *see* : to *know* *what* is *where*
by *looking*

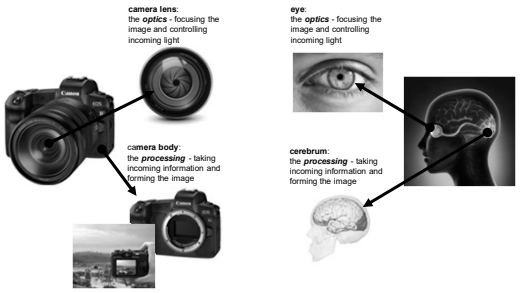
- Aristotle

The only thing worse than being blind is having sight but no vision

- Helen Keller

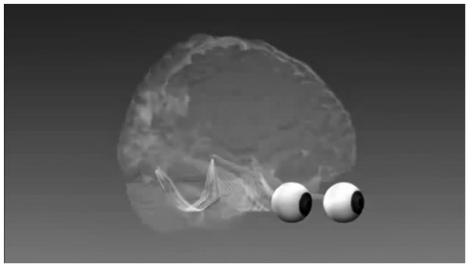
12

The Visual System as a Digital Camera (An Analogy)



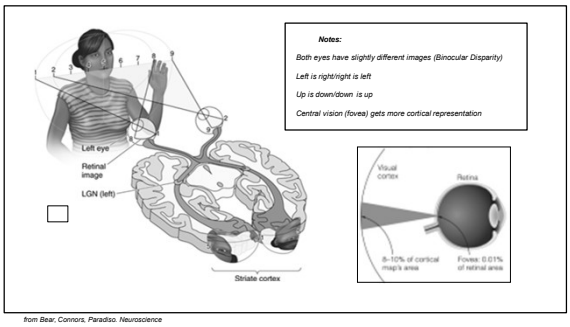
13

The Human Visual System
(Afferent Pathways)



14

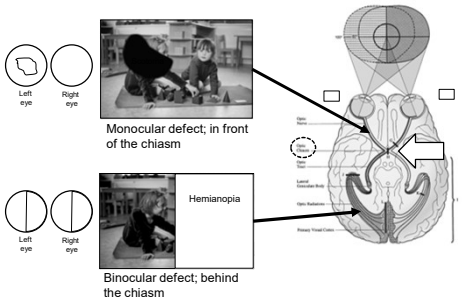
The Anatomy of Visual Pathways: Retinotopic Organization



from Bear, Connors, Paradiso. Neuroscience

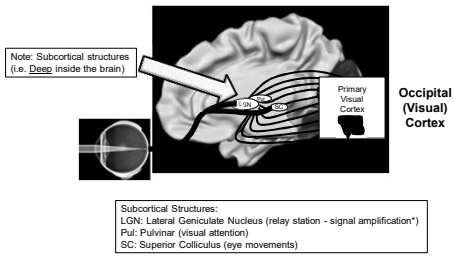
15

The Anatomy of Visual Pathways: Clinical Manifestations



16

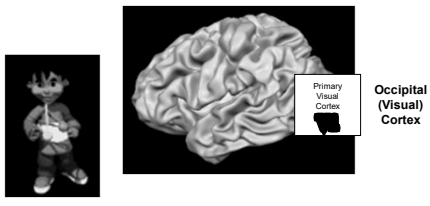
Retinal-subcortical-cortical Component (Afferent visual pathway): neural signals leaving the eye via the optic nerve are sent to the thalamus (lateral geniculate nucleus) and then sent along the optic radiations to the occipital primary visual cortex (V1) for early processing



Subcortical Structures:
LGN: Lateral Geniculate Nucleus (relay station - signal amplification*)
Pul: Pulvinar (visual attention)
SC: Superior Colliculus (eye movements)

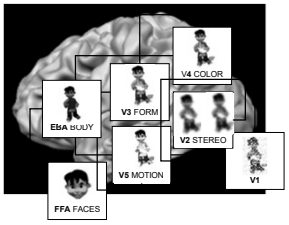
17

Cortico-cortical Component: higher order visual cortical areas are responsible for further analysis and eventual integration



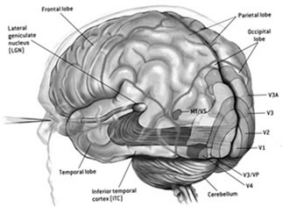
18

The Visual System…Feature specialization

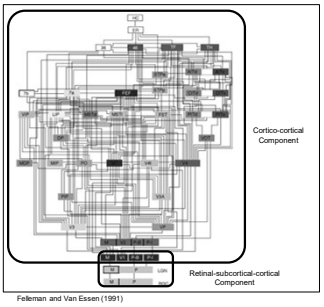


19

The Visual System: "Simplified View"



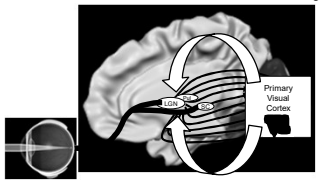
Approximately 30 different cortical areas that contribute to visual perception.



Felleman and Van Essen (1991)

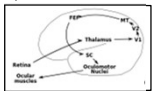
20

Cortical Feedback Component (Efferent visual pathway): neural signals leaving the cortex and returning to the thalamus or earlier cortical areas to modulate incoming information.

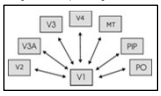


Occipital (Visual) Cortex

Eye movement control



Integrated cortical processing

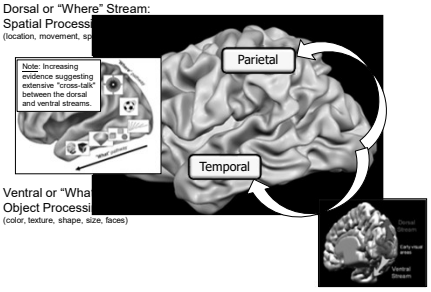


21

The Human Visual System: A Division of Labor

Ungerleider and Mishkin (1983)

Dorsal or "Where" Stream:
Spatial Process
(location, movement, sp



Ventral or "Wha
Object Processi
(color, texture, shape, size, faces)

22

The case of damage to the Ventral Stream

Object Processing Disorders

Visual Agnosia
from Greek: *a-* (not or lack of) + *gnōsia* (from *gnôsis* "knowledge")

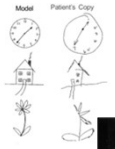
Many types: e.g.
- prosopagnosia (faces)
- object agnosia (may be very selective, e.g. animate objects)

23

The case of damage to the Dorsal Stream

Spatial Processing Disorders

Neglect Syndrome



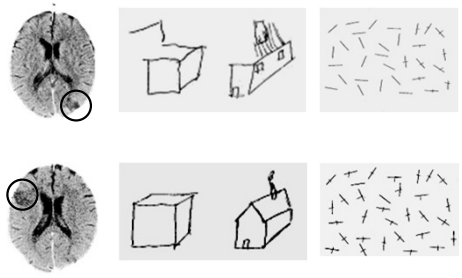
from Raichle and Posner, 1994: Images of Mind

The Milan Square Experiment
Bisiach and Luzzatti (1978)

simultaneous agnosia - extinction

24

Clinical Case of Neglect

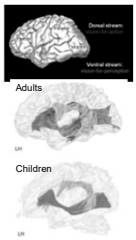


Vuillamiere et al. 1996

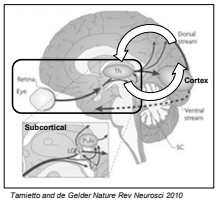
25

Human Visual Development:

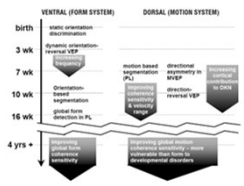
- Early vision (i.e. first few months) is largely subcortical
- Progressively integrated with and dominated by cortical processing during the first year
- Ventral (shape/what pathway) appears to develop before the Dorsal (spatial/motion/where) system
- "Dorsal Stream Vulnerability" is a common feature across neurodevelopmental abnormalities



Perani et al. PNAS 2011



Tamietto and de Gelder Nature Rev Neurosci 2010



Braddick et al. Neuropsychologia 2003

26

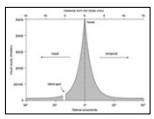
Vision is an Active Process

We don't notice (or process) the majority of the visual information that enters the eyes.

- There are limits to the processing capacity of the visual system/brain.

The eye does not provide high resolution (i.e. fine detailed) information across the entire field of view.

- Central vision (central 2 degrees) provides high resolution and vivid color (cone photoreceptors)
- Peripheral vision provides low resolution, *but* is very sensitive to motion, black & white, and low light (rod photoreceptors)



www.cogsci.nl/Sebastiaan Mathôt.

27

Vision is an Active Process

Solution: Move the eyes!
- Rapid movements of the eyes sample the entire visual scene

Over time, the brain "stiches" together a high resolution representation of the visual scene.

Eye movement patterns reflect the content and saliency of the visual scene.

In reality, the brain decides where to look and what we should pay attention to.

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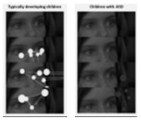
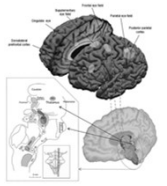
Visual Search (Eye Tracking) as a Proxy for Functional Vision Performance

Yarbus



Zilbovicius et al. **Open Journal of Psychiatry 2013**

*Highly integrated, large-scale network:
- object/target identification
- spatial processing
- attention processing (overt and covert)
- ocular motor control
- memory
- decision making
- goals and reward mechanisms

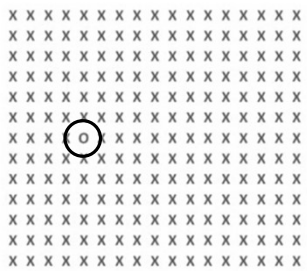


Modified from Petzold A, Plaine M, Fraldon M, Riordan-Eva P, Bronstein AM, Grealy MA, Plant GT. Neuroophthalmology. 2009;33:217–236.)

*Key Brain Areas:
- Posterior parietal cortex (IPS, SPL, IPL)
- Frontal cortical areas (frontal eye fields)
- Temporal cortical areas (STG)
- Early occipital visual areas
- Subcortical areas (pulvinar, superior colliculus)
- Oculomotor nuclei

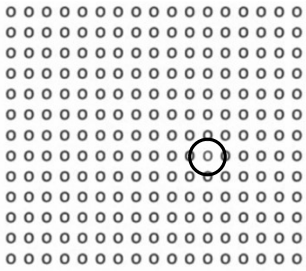
29

Find the Blue **O**



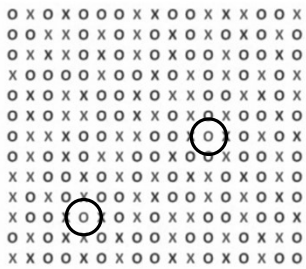
30

Find the Blue **O**



31

Find the Blue **O**



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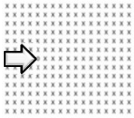
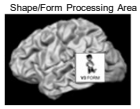
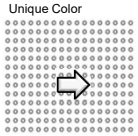
Unique Shape



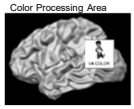
Shape/Form Processing Area



Unique Color



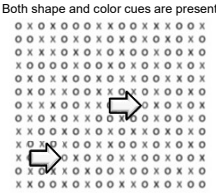
Color Processing Area



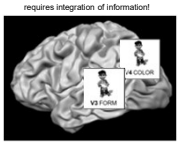
33

Visual Perception Requires Coordination in Space and in Time… "Perceptual Binding"

Both shape and color cues are present



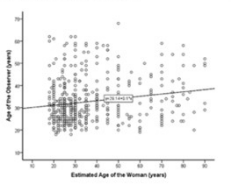
Shape and Color processing areas have to talk to each other…this requires integration of information!



34

"My Wife and My Mother-in-Law" W.E. Hill 1915

Perception of an ambiguous figure is affected by own-age social biases



35

Cognitive Priming: Visual Example

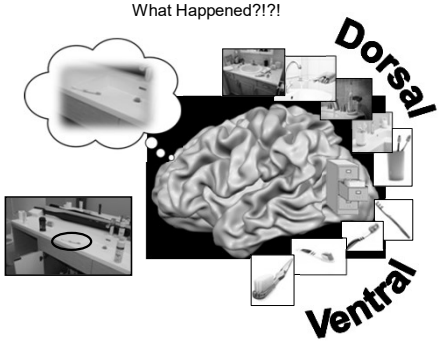
36

Your Task: Can you spot the toothbrush in the messy bathroom?

Why We Miss Objects That Are Right in Front of Us
By HEATHER MURPHY OCT. 6, 2017
The New York Times

37

What Happened?!?!



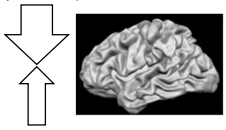
38

"the brain is inherently predictive"

Sensory expectations/knowledge accessing prior memories

MEANING

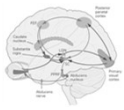
(Top Down Influence)



(Bottom Up Influence)

Sensory input/incoming data (e.g. visual) Data-based processing

SALIENCY



Kandel et al. Principles of Neural Science, 5th Ed

"We perceive what we know"
How you see the world is very much influenced by the world you have already seen

William James
Rao et al. Nat. Neurosci. 1999
Friston, K. Philos. Trans. R. Soc. 2005
Emberson et al. Current Biology 2017
Carbon CC. Front Human Neuroscience 2014

39

Vision is an Active Process: How Much Information Can We Handle?

40

The Effect of Task Load
(From Goldstein)

Perceptual capacity in reserve	No perceptual capacity in reserve	No perceptual capacity in reserve
Resources used by low-load primary task	Resources used by high-load primary task	Resources used by low-load primary task but with less perceptual capacity

- Low load tasks that use few cognitive resources may leave resources available for further task processing.
- High load tasks that use all the person's cognitive resources exhaust available resources and/or don't leave extra resources for further processing.

Solution: Decrease task demand and/or increase cognitive resources

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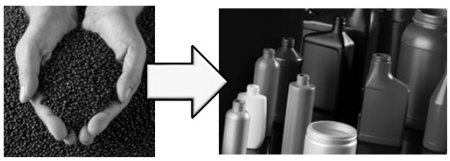
Neuroplasticity:

(noun) "The quality of being easily shaped or molded"

origin Greek: "plastikos" meaning molded, *from "plassein": to mold or to shape*



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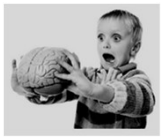
Neuroplasticity:

The ability of the brain to change its structural and functional organization in response to development, experience, the environment, or damage…

…it is not a "guaranteed fix"; it is the inevitable consequence of how the brain works throughout a lifetime.



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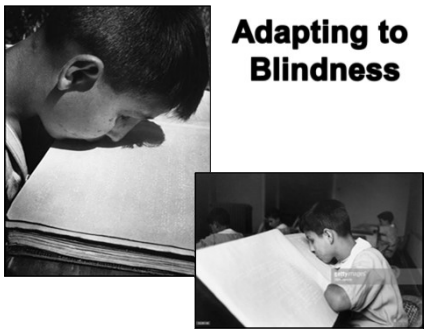

David Seymour. "Blind Boy Reading With His Lips". 1948. Corcoran Gallery of Art, Washington, D.C.

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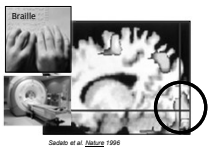
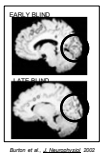
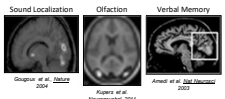
Brain and Visual Development: Neuroplasticity in the setting of Ocular-based Blindness



Sadato et al. Nature 1996



Burton et al., J. Neurophysiol. 2002



Gougoux et al. Nature 2004

Kupers et al. Neuroscience 2011

Amedi et al. Nat Neurosci 2003

The occipital visual cortex as the site of compensatory non-visual behaviors in profound ocular blindness

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Brain and Visual Development: Neuroplasticity in the setting of Brain-based Visual Impairment

Why this Matters…

(Re)Habilitative and education strategies developed for individuals with profound blindness or low vision due to ocular causes…are not necessarily effective (and may be even detrimental) in the setting of brain-based blindness and visual impairment.

- Baker-Nobles and Rutherford, 1995
- Farrenkopf, et al., 1997
- Gordon, 1968
- Groenveld, et al., 1990

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1. The Timing and Localization of Visual Impairment/ Blindness:

   - congenital ocular causes (e.g. retinopathy of prematurity)
   - acquired ocular causes (e.g. macular degeneration)
   - acquired brain causes (e.g. stroke)
   - congenital brain causes (e.g. CVI)

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2. Adulthood vs. Childhood Visual Impairment

- Globally, this is at least 2.2 billion people have a near or distance vision impairment. In at least 1 billion of these cases (i.e. half), vision impairment could have been prevented or has yet to be addressed.

The majority of people with vision impairment and blindness are over the age of 50 years. However, vision loss can affect people of all ages.

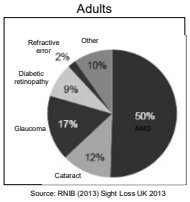
The impact of childhood blindness can be very detrimental to development.

Definitions

Vision impairment (Distance):
- Mild: visual acuity worse than 6/12 to 6/18
- Moderate: visual acuity worse than 6/18 to 6/60
- Severe: visual acuity worse than 6/60 to 3/60
- Blindness: visual acuity worse than 3/60

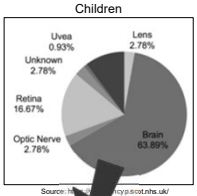
World Health Organization

Adults



Source: RNIB (2013) Sight Loss UK 2013

Children



Source: http://www.moorfields.nhs.uk/

Cerebral Visual Impairment (CVI)

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The number one individual cause of pediatric blindness/visual impairment is not due to disease of the eye. It is because of developmental damage to the brain.

Impact on assessment, diagnosis, and education…

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