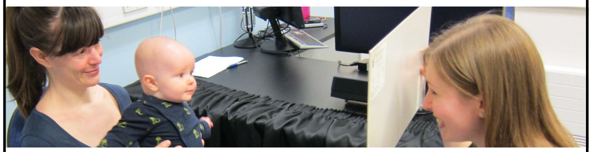
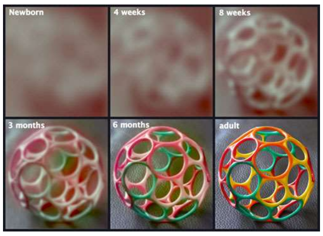


The development of spatial vision in human infants

Dr Pete Jones
p.r.jones@ucl.ac.uk

1

Human infants are born (legally) blind



www.tinyeyes.com

2

Lecture Overview

1. Methods of studying infant visual development
2. A case study: Visual Acuity [VA]
3. What mechanisms underlie the development of VA?

3

I. Methods of measuring human infant vision

4

Basic overview of methods for infants

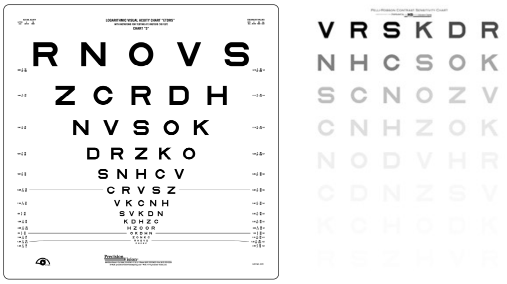
- Behaviour: Eye movements
  - Cortical/Saccadic: Preferential looking
  - Reflexive: Optokinetic nystagmus
- Electrophysiology
  - EEG/VEP (Electroencephalography)
  - ERG (Electroretinography)
- Physiology
  - *In Vitro* histology, using staining
  - Non-invasive *In Vivo* imaging, using OCT / SLO

5

METHODS:
FUNCTIONAL/BEHAVIOURAL MEASUREMENTS

6

In adults…



7

Key behavioural framework: "**Preferential Looking**"

- "Did the infant see the stripes?"
- Test grating presented against equiluminant background (invisible if not resolved)
- Position of reference and test randomised
- (Typically) baby's response classified by human operator, by whatever means

Mayer et al, *IOVS*, 1995
Teller et al, *Dev Med Chld Neurol.*, 1986

8

Key behavioural framework: "**Preferential Looking**"

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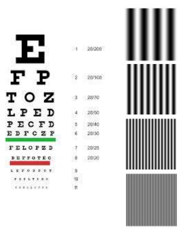
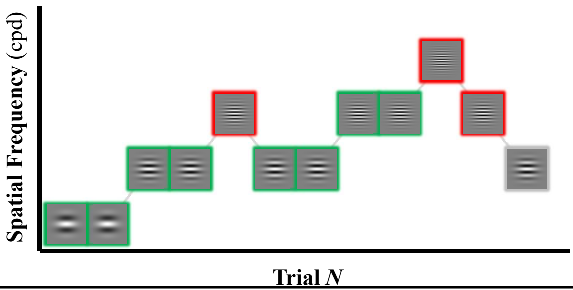


Mayer et al, *IOVS*, 1995
Teller et al, *Dev Med Chld Neurol.*, 1986

9

Threshold determined by a staircase

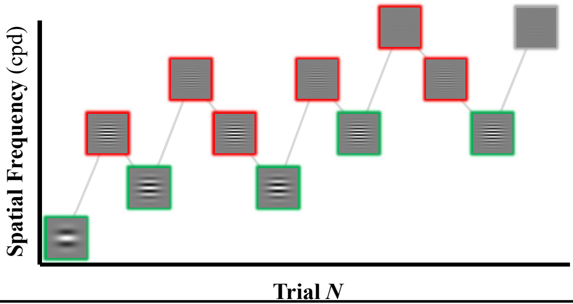
2-Up-1-Down (70.7%) *transformed* staircase (Levitt, 1971)



10

Threshold determined by a staircase

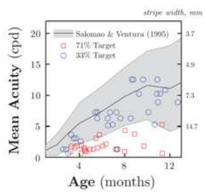
Up-2-Down-1 (33.3%) *weighted* staircase (Kaernbach, 1991)



11

Threshold determined by a staircase

- Choice of staircase parameters is vital
- Important to not just copy from 'adult' papers, as infants/children behave in qualitatively different ways
- In particular: high lapse rates (as much as 33%!)
- Failure to account for these population-differences can be the difference between a test giving useful results or meaningless noise



Jones et al, *JoV*, 2015

12

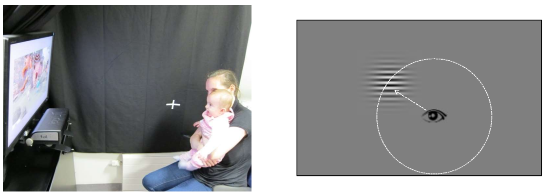
Key behavioural task: "**Preferential Looking**"

13

Key behavioural task: "**Preferential Looking**"

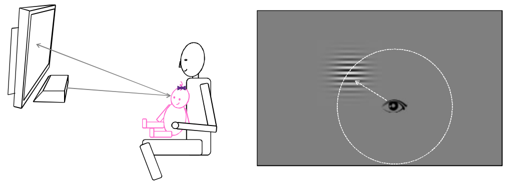
14

Key behavioural task: "**Preferential Looking**"



15

Key behavioural task: "**Preferential Looking**"



Jones et al, *IOVS*, 2015

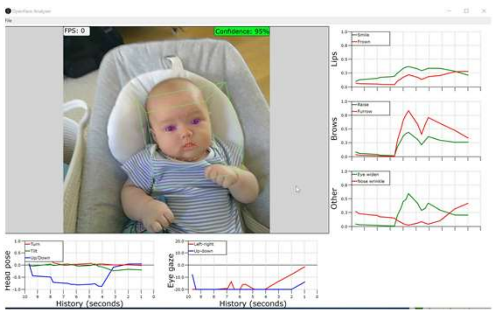
16

Key behavioural task: "**Preferential Looking**"

Jones et al, *IOVS*, 2015

17

Key behavioural task: "**Preferential Looking**"



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Key behavioural task: "**Optokinetic Nystagmus**" [OKN]

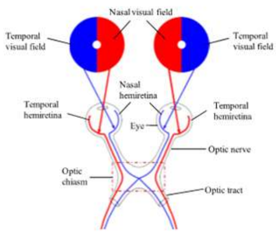
- "Did the stripes elicit OKN?"
- Typically a slow "tracking" movement in the direction of stimulus motion, followed by a fast, saccadic movement in the opposite direction.
- Can be measured for a single set of stripes moving in one direction. Alternatively, a fixed 'standard' and a variable 'reference' can be placed in counterphase (motion nulling).

Lewis et al, *Vis Res*, 2000

19

Key behavioural task: "**Optokinetic Nystagmus**" [OKN]

- PROS:
  - Reflexive – so perhaps less affected by mood/attention (!)
  - Monocular nasal-to-temporal OKN can be selectively indicative of immaturity in the cortex or optic chiasm
- CONS:
  - Requires wide-field presentation (cumbersome, cannot assess local visual-field function)
  - Not always easy to elicit



Lewis et al, *Vis Res*, 2000

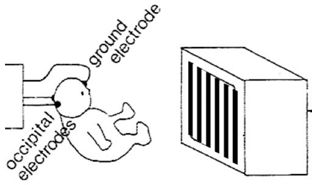
20

METHODS:
ELECTROPHYSIOLOGY

21

Key physiological measure: VEP

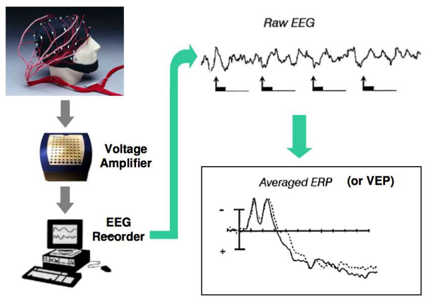
- Visual-evoked potential
- A 'vision-specific' name for a Event Related Potential [ERP]



Sokol, *Vis Research*, 1978
Norcia & Tyler, *Electrophys. & Clin. Neurol.*, 1985

22

Recording EEG Activity



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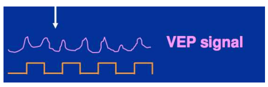
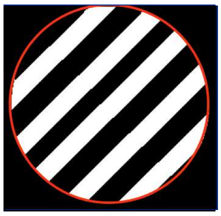
Steady-state, Phase-reversal, VEP

- Alternate phase of stripes at a fixed rate
- Look for correlated neural activity with the same periodicity





24

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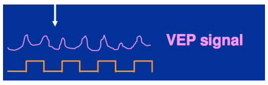

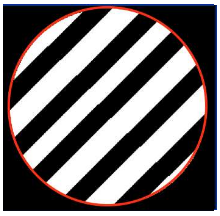

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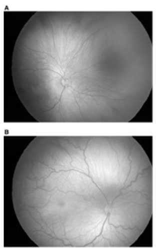
METHODS:
PHYSIOLOGY

26

In humans, physiology historically only studied in vitro (“in glass”)

- Vasculature
- Thickness of retinal cell layers
- Cell counts / density



/wo ROP

/w ROP

Wilson et al, *Retina*, 2008

27

In humans, physiology historically only studied in vitro (“in glass”)

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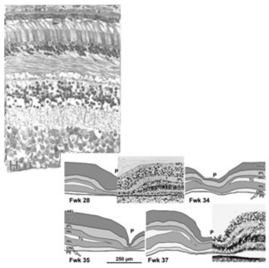


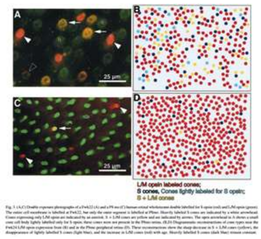
Hendrickson & Drucker, 1992

Hendrickson et al, 2012

28

Traditional performed in vitro (“in glass”)

- Vasculature
- Thickness of retinal cell layers
- Cell counts / density



Cornish et al, *Exp Eye Res*, 2004

29

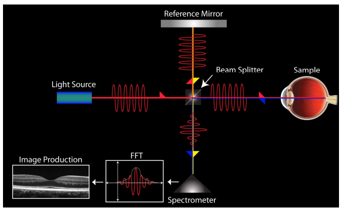
However, increasingly being done in vivo using retinal imaging (!!)

- Retinal imaging allows the physiology of the retina to be visualised in awake, behaving humans
- Currently two main ‘flavours’
  - Optical Coherence Tomography (OCT)
  - Scanning Laser Ophthalmoscope (SLO)
    - » *And now:* Adaptive Optics SLO (AO-SLO)

30

Optical Coherence Tomography (OCT)

- Similar to an ultrasound, except it uses light waves to determine the reflectivity of cells in the retina



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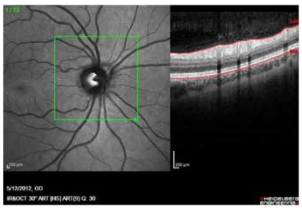
Optical Coherence Tomography (OCT)

- Build up ‘slices’ to get a full 3D picture of the retina



32

Optical Coherence Tomography (OCT)

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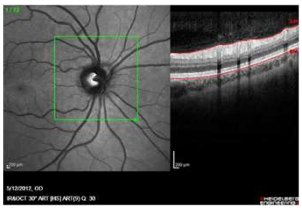

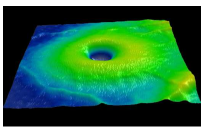

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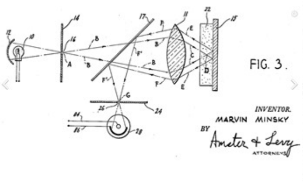
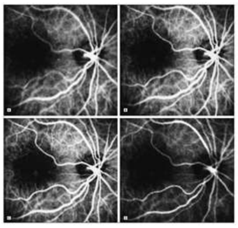
Scanning Laser Ophthalmoscope (SLO)

- Based on confocal microscopy
- Limited by optical aberrations in the eye





Freeman et al, *Arch Ophthalmol.*, 1998

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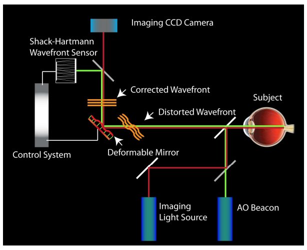
Adaptive Optics SLO (AO-SLO)

- A set of tools to correct or control aberrations in [any] optical system



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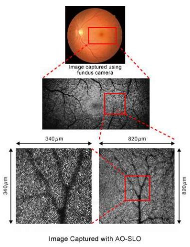
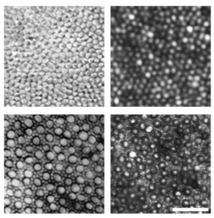
Adaptive Optics SLO (AO-SLO)

- A set of tools to correct or control aberrations in [any] optical system
- Allows individual photoreceptors to be studied





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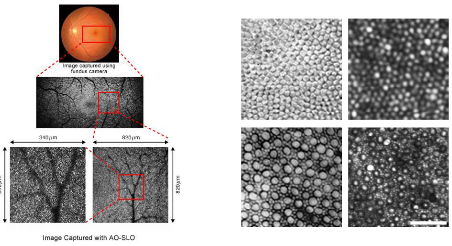

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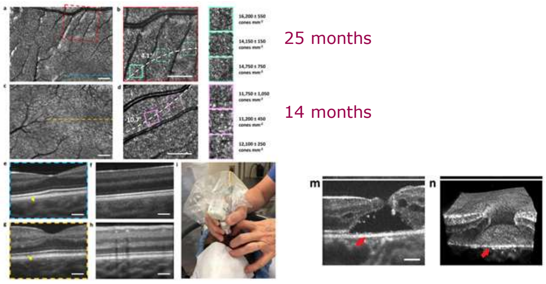

LaRocca et al, *Nat. Photonics.*, 2016

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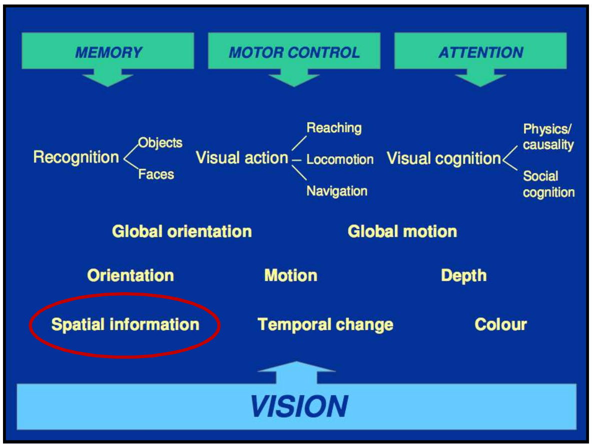
II. Case Study:
The development of spatial vision (acuity) during infancy

39



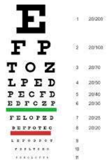
40

Most basic function of vision: transmitting spatial information

- Acuity is the one key measure
- In adults:

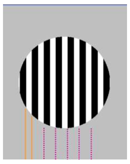
recognition acuity =

6/6 (or 20/20 in USA)



Resolution acuity =

- ~30cycles/deg



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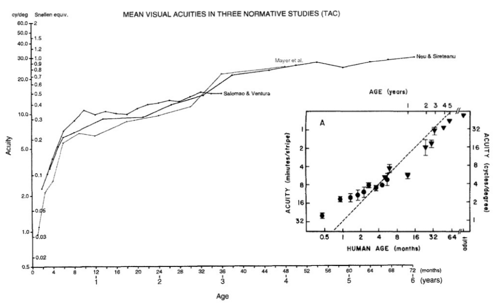
Behavioural data (1/2): Humans

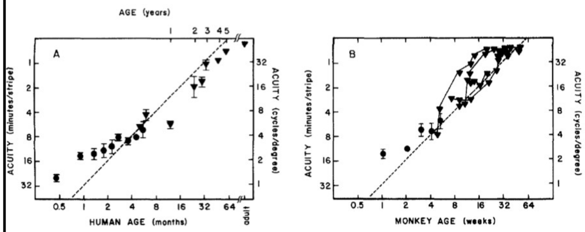


Neu & Sireteanu, *Strabismus*, 1997

42

Behavioural data (2/2): Macaques

- In first year around ~1cpd per month in humans
- Similar developmental shape, but around ~1cpd per *week* in macaques



Teller, 1981

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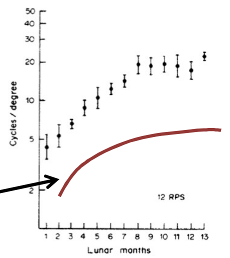
Electrophysiological data

- Shows "better" performance than is exhibited behaviourally
- NB: only shows that there is input to cortex, not whether that information is used/extracted



Rough overlay of behavioural data from Neu & Sireteanu (1997)

Fig. 7. The mean sweep VEP acuity with 95% confidence bands in 1 month (lunar) increments for the data of Fig. 6.

Norcia & Tyler, 1985

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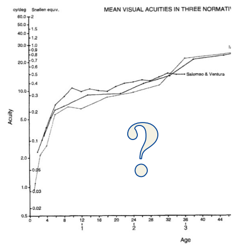
III. Mechanisms underlying the development of spatial vision

45

Acuity increases with age – why?
What limits the development of VA?

- Optical inefficiency?
('transmission error')
- Transduction inefficiency?
('encoding error')
- Neural inefficiency?
('decoding error')



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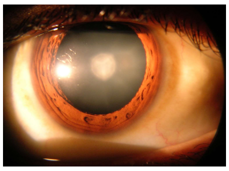
Optical: Is light falling on the eye being blurred or occluded?

- ***Clarity of ocular media?*** (Cornea, Lens, and Humours)



- Some abnormalities in neonates, and some extreme clinical cases, but generally clear when inspected by ophthalmoscopes (Howland, 1993)

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Optical: Is light falling on the eye being blurred or occluded?

- ***Reduced aperture?***
- Pupil size is smaller, and the eyeball is shorter and smaller – smaller area of the retina receives input
- But acuity is mediated by the fovea (centre)

48

Optical: Is light falling on the eye being blurred or occluded?

- ***Refractive error?*** An inability to accommodate?
- Accommodation not mature at birth (can focus at 75cm but not at 150cm; Braddick et al, 1979)
- But most acuity testing done at < 40cm
- Acuity roughly constant when testing difference manipulated (30–150cm; Salapatek et al, 1976)
- May be the opposite – less VA limits accomodation

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Optical: Is light falling on the eye being blurred or occluded?

- ***Motor noise?***
- Retinal image can't be too still (Troxler fading), or too variable
- Controlled subcortically (though potentially with top-down inputs)
- Some evidence of immature motor control (slower saccadic onset; poor binocular-yoking in first month), but grossly good from birth.

50

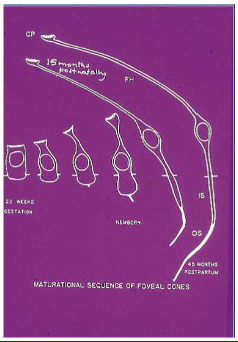
Optical: Is light falling on the eye being blurred or occluded?

- Unclear ocular media?
  - No
- Reduced aperture?
  - No
- Refractive error?
  - No
- Motor noise?
  - No

51

Transduction: Is the retina failing to convert light to nerve impulses?

- Cone cells are immature in two key ways.
- **Firstly**, the outer segment (OS) is shorter
- OS contains the photopigment
- Around 10 times fewer isomerisations per incident quanta



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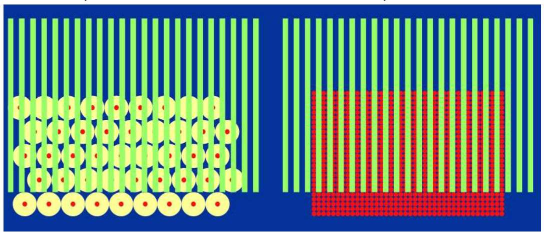
Transduction: Is the retina failing to convert light to nerve impulses?

- **Secondly**, the inner segment is fatter, allowing for less dense packing

~6µm at birth versus ~1.9µm in adults



53

Transduction: Is the retina failing to convert light to nerve impulses?

- When Banks & Bennet (1988) performed an *ideal observer analysis*, they found that a substantial loss of VA is due to preneural factors
- ***However:***
  - Only predicts ~2-octave loss of grating acuity (relative to adults), whereas neonates exhibit ~5-octaves
  - The developmental profiles don't match. Kiorpes and Movshon (2004) found changes in monkey photoreceptors were confined to the first four weeks
- Substantial inefficiency unaccounted for…

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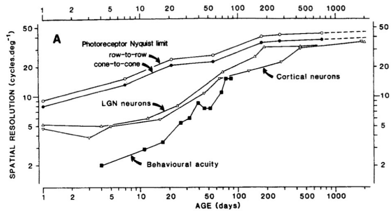
Cortical development

- Evidence of improving selectivity along the visual hierarchy
- Increased physiological receptive fields (Lack of appropriate excitatory/inhibitory connections?)



Jacobs & Blakemore, *Vis. Research*, 1988

55

Cortical development

- Evidence of wide-spread neural development
- The mass of the brain increases postnatally, from 350g to 1350g (~x4)
- Rapid expansion of primary visual cortex (BA17) volume during first four months postnatal (Huttenlocher & Courten, 1987)
- N.B. But neural numbers remain roughly constant (Leuba & Garey, 1987)… what's changing… ?

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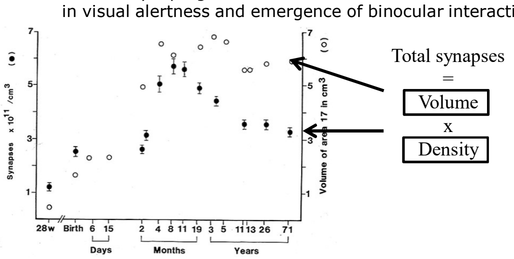
Cortical development

- Massive increase in synaptic connectivity
- Burst in synaptogenesis correlates with a sudden increase in visual alertness and emergence of binocular interactions



Huttenlocher & de Courten, *Human Neuroiol.*, 1987

57

V. Summary

58

Summary

- Behavioural (FPL), electrophysiological (VEP), in vitro histology, and in vivo retinal imaging methods can all be used to asses infant vision
- Spatial vision (visual acuity) shows very rapid development during first few months (1cpd/month), then slower development towards maturity by ~4 years
- The limiting factors driving development are partly retinal (immature and sparse photoreceptors), and partly neural (lack of connectivity)

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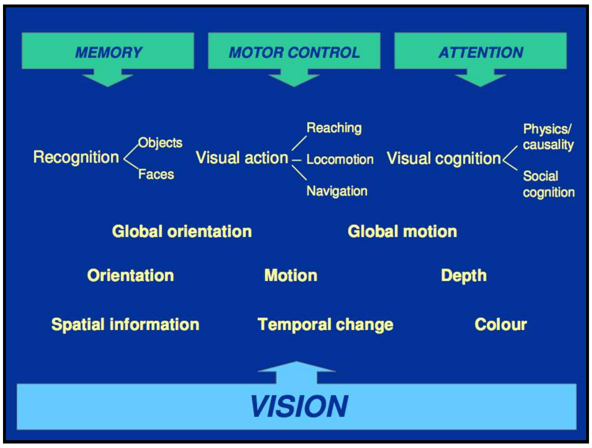

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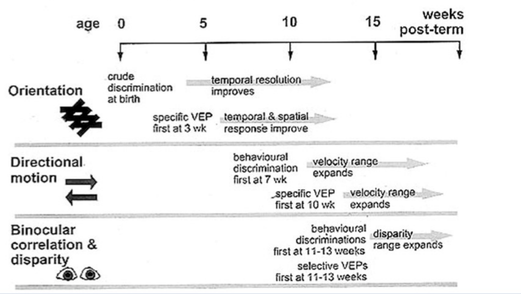
Wider context: Other visual abilities



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