Visual development in babies and infants

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Vision

- a major function of the primate brain
- vision develops rapidly in early life and serves as a base for development of action, cognition, communication, social interactions

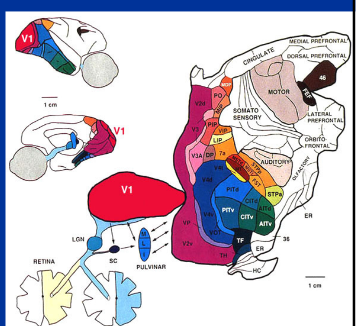


Figure 19. Much of V1 is located in the calcarine sulci and its relationship to other brain areas is best shown by unfolding the brain and showing it flattened open. The visually responsive areas of the macaque monkey are shown in color. From Van Essen et al. (1992).

MEMORY | **MOTOR CONTROL** | **ATTENTION**

Recognition: Objects, Faces

Visual action: Reaching, Locomotion, Navigation

Visual cognition: Physics/causality, Social cognition

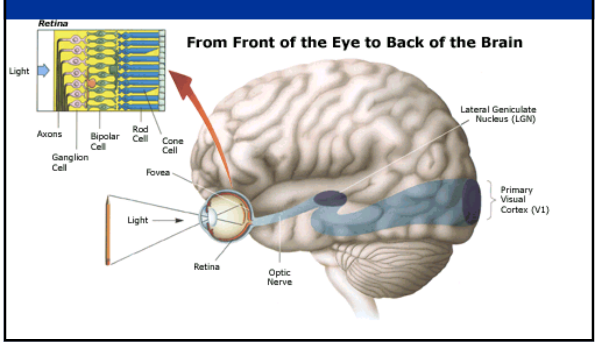
Global orientation | **Global motion**

Orientation | **Motion** | **Depth**

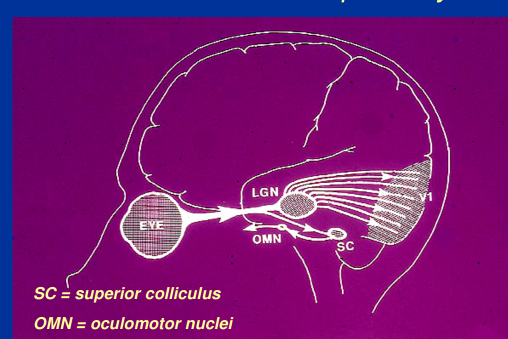
Spatial information | **Temporal change** | **Colour**

VISION

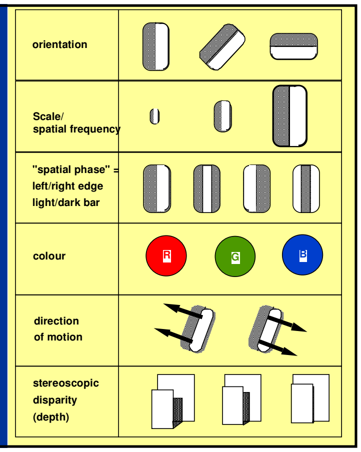
Key features of the visual system: *the retina-geniculostriate pathway*



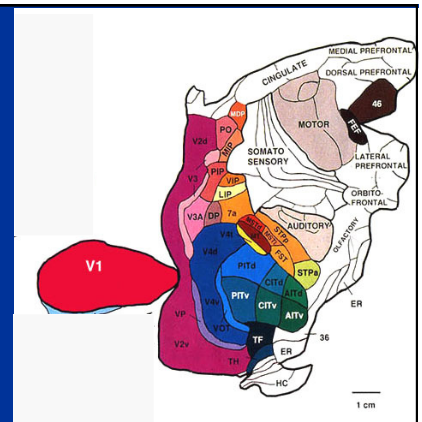
Key features of the visual system: *subcortical & cortical pathways*



Key features of the visual system: *selectivity of cortical neurons*



Key features of the visual system: *specialised cortical visual areas*

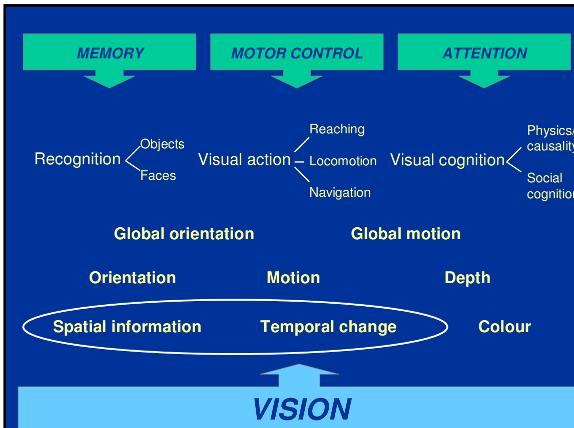


Visual development: Outline

1. Basic visual information - early stages of the visual pathway
1.1 Spatial information
1.2 Temporal information

2. Later stages
2.1 Orientation
2.2 Motion

3. Integration across larger areas
3.1 Global form and global motion



Most basic function of vision: transmitting spatial information

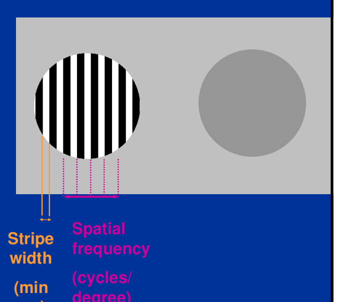
measure =
visual acuity

'Normal adult acuity' =

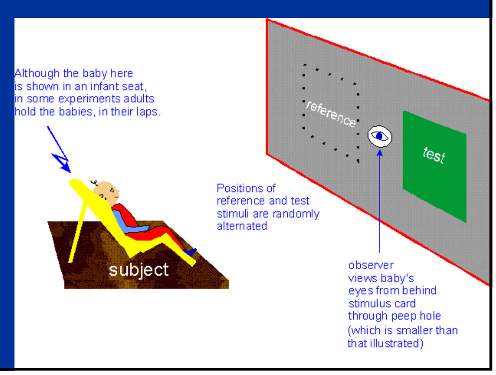
~1 min arc

~ 30 cycles/deg

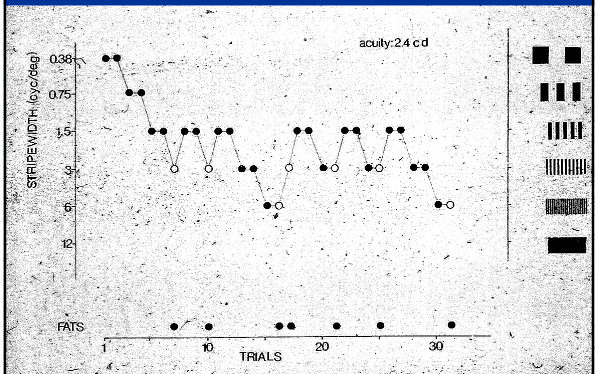
"6/6" or "20/20"



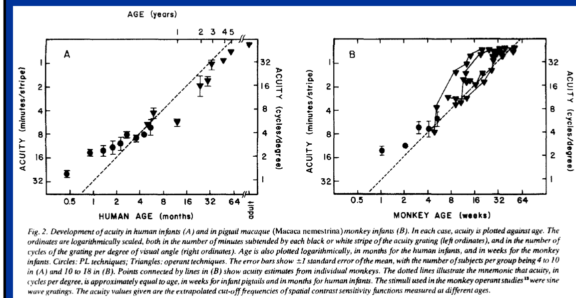
Forced-choice preferential looking (FPL)



Staircase method for acuity threshold

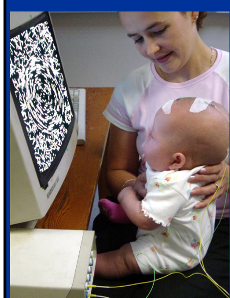


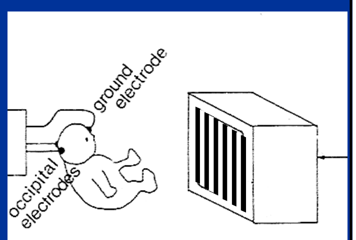
Acuity increases with age



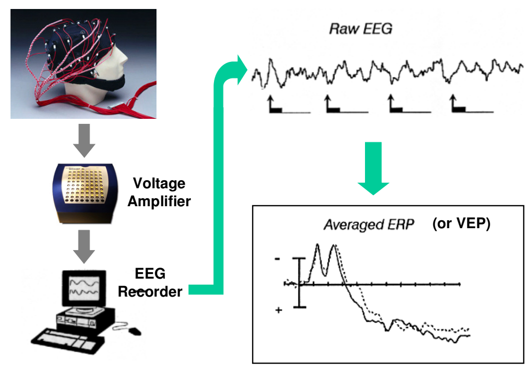
Teller (1981) – human and macaque grating acuity using PL and operant techniques

Visual evoked potential (VEP) – same as ERP

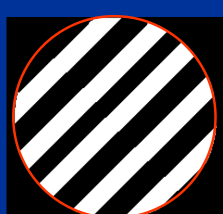




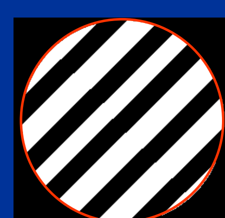
Recording EEG Activity



Phase-reversal (pattern reversal) VEP



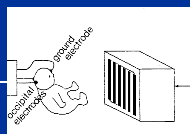
Phase-reversal (pattern reversal) VEP



Phase-reversal (pattern-reversal) visual evoked potential (VEP)

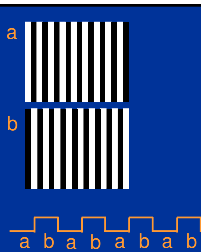
amplification

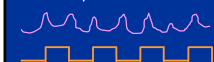
signal averaging, time-locked to phase-reversals



a

b





VEP signal

Phase-reversing grating

(2-10 cycles/sec)

Statistically significant VEP to stripe reversal shows input activity to cortex – though not necessarily cortical function

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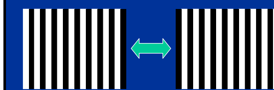
“Sweep VEP”

Regan (1977)

Temporally modulated pattern



5Hz or 10Hz

Frequency is systematically changed (swept) over a large range.

Can measure amplitude of VEP response as a function of frequency, and extrapolate the highest frequency that is processed (i.e. acuity) from this

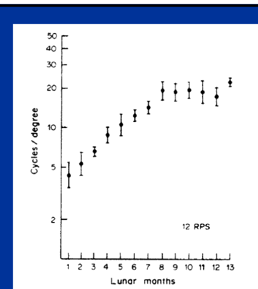


Fig. 7. The mean sweep VEP acuity with 95% confidence bands in 1 month (lunar) increments for the data of Fig. 6.

Norcia & Tyler (1985)

Indicates 2-3x better acuity at 1mo. than PL – but only that there is input to cortex, not necessarily cortical processing or perception

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Acuity increases with age –why?

Limits on developing visual acuity

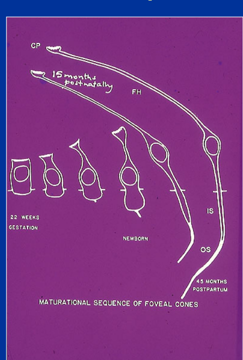
- Optical blur
  - clarity of media
  - refraction
- Receptor density & efficiency
  differentiation of the fovea
- Neural development

Limits on developing visual acuity:
Optical blur

- clarity of media
- refraction & accommodation

Not generally the limiting factors on infant acuity

Limits on developing visual acuity:
Receptor density & efficiency



- OS = outer segment; contains photosensitive pigment
- short OS = inefficient at detecting light
- fat inner segment (IS) = cones aren’t tightly packed = poor spatial sampling of the image
- Development of long fibre = cones displaced to allow dense packing in foveal pit

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Limits on developing visual acuity:
Receptor density & efficiency

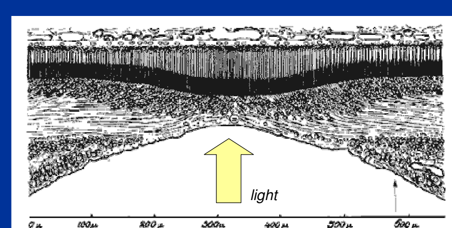
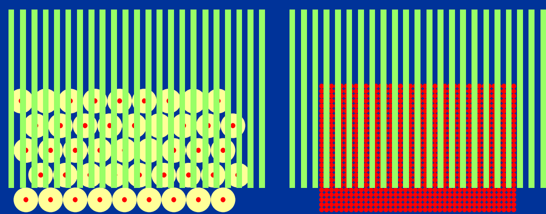


FIGURE 4.6 Central fovea of the human retina. (From Polyak, 1957.)

Maximum acuity provided by fovea – displaced cell bodies allow dense packing and minimal obstruction of light to cone outer segments

photoreceptor density, image sampling & development of acuity



coarse spacing (newborn) – pattern under-sampled

fine spacing (adult)– pattern adequately sampled

Banks & Bennett (1988)

- Sampling argument combined with poor efficiency due to short outer segments
- Calculated in comparison with adult and 'ideal observer' model
- May account for overall change, but
    - both adult and infant fall far short of ideal observer – little idea of factors
    - poor account of acuity changes during infancy, especially first 3 months
- Other, more central, changes are going on

Limits on developing visual acuity: Neural development

- myelination of visual pathways
  - what are functional consequences?
- development and distribution of cortical neurons
- developing connectivity in cortex (and elsewhere)
  - increasingly complex dendritic and axonal processes

Development and distribution of cortical neurons

- cell proliferation
- cell migration
- cell differentiation into different structural types

All three processes are complete before birth

Although all cells are born before birth, the mass of the brain increases postnatally from 350 g – 1350 g (approx x 4)

This increase must include

- myelin
- fibres and synapses associated with increased connectivity

Connectivity determines function

Synapse numbers increase, then decrease

(Huttenlocher)

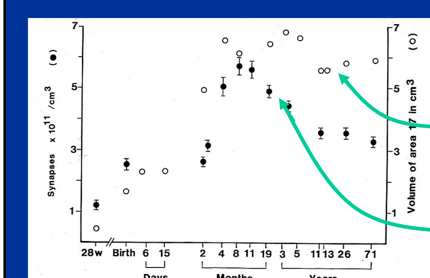
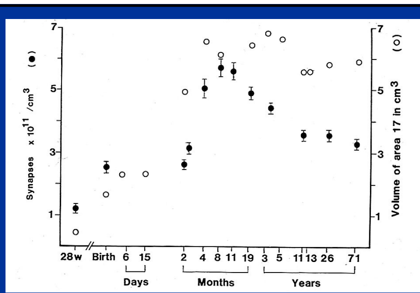


Fig. 4. Mean synaptic density values for all layers of area 17 are indicated by the closed circles (left-hand scale). Each point represents the mean of several thousand counts. Vertical bars represent the standard error of the mean of 6 separate synapse counts in the same brain in strips of cortex 3 μm in width. The open circles are the values for volume of the right area 17 (right-hand scale). Age is plotted on a logarithmic scale. (From ref. 35).

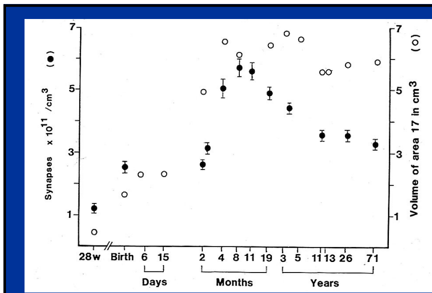
Total synapses = volume x synapses/cm^3



Processes of

(a) growth of dendrites and synaptic terminals

(b) selective pruning of connections



Synaptic increase is seen everywhere in cortex.

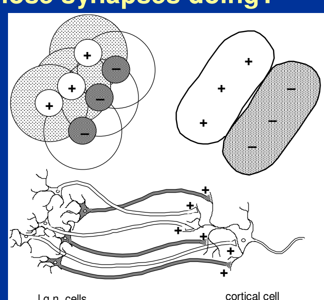
What are its implications for visual function?

What are all those synapses doing?

Connectivity determines receptive field structure – and therefore function

e.g.

orientation selectivity



Hubel & Wiesel 1960's model – probably too simple – intracortical connections are important also!

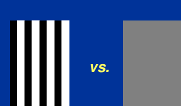
Spatial information: Summary

- Visual acuity shows very rapid development in first few months of life, then slower development towards adult levels by 3-4 years
- Underlying changes in photoreceptor organization, neural connectivity and myelination

Temporal change

Changes over time provide a basis for detecting **movement** in the visual field

- Change in space (at a single time) – basic measure: *acuity*

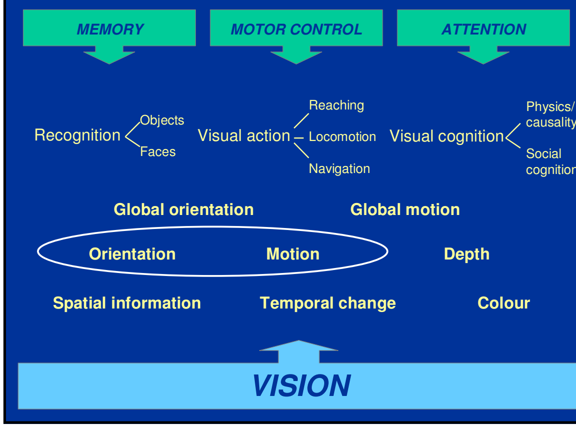


- Change in time (at a single location) – basic measure: *critical fusion frequency (CFF)*

- Behaviourally (pref looking), infants' critical fusion frequency was strikingly mature (Regal 1981): 40Hz (75% of adult) at 4 weeks; indistinguishable from adult at 12 weeks.
- Much more mature than acuity. Makes sense as electroretinograms (ERGs) show newborn cones to respond at up to 75Hz – so this is not a constraint.
- However, EEG measures of flicker information reaching visual cortex show much lower critical frequency. (Apkarian 1993, Morrone et al 1996).
- May be that latencies are long and variable due to incomplete myelination, leading to out-of-phase signals in cortex that (1) do not give coherent EEG, but (2) could still drive a behavioural response - see Atkinson & Braddick OVS 2009

Review

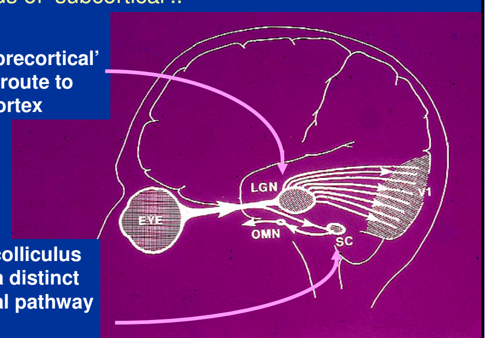
- We have seen how sensitivity to **spatial and temporal changes** in luminance (and wavelength / colour) develops in the first few months of life
- These provide the building blocks for detecting the **orientation, motion** and **depth** of visual patterns
- This requires increasingly sophisticated neural information processing – dependent on cortex (V1)



ORIENTATION processing

Two kinds of 'subcortical'..

LGN is 'precortical' – on the route to striate cortex



Superior colliculus is part of a distinct subcortical pathway (but also interconnected with cortex)

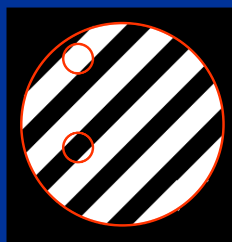
Neither LGN or SC show orientation selectivity independent of cortex

cortical neurons – and not precortical - show selective sensitivity to :

- **orientation**
- **direction of motion**
- **binocular disparity (stereopsis)**

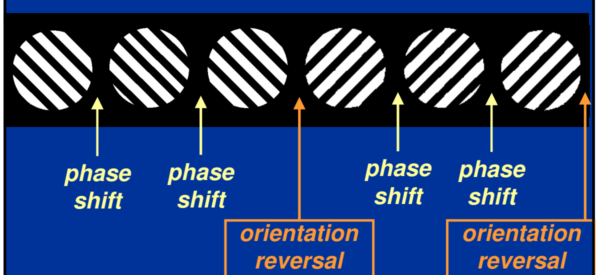
Development of orientation selective cortical neurons – orientation-reversal VEP

Simple orientation-reversal

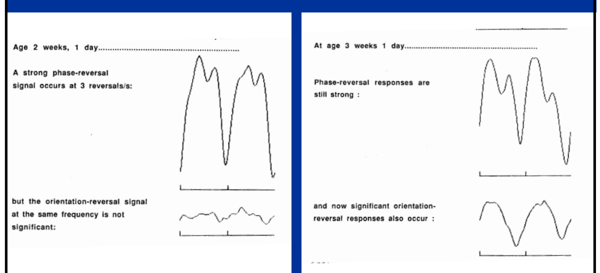


Simple orientation-reversal

ORIENTATION- REVERSAL SEQUENCE

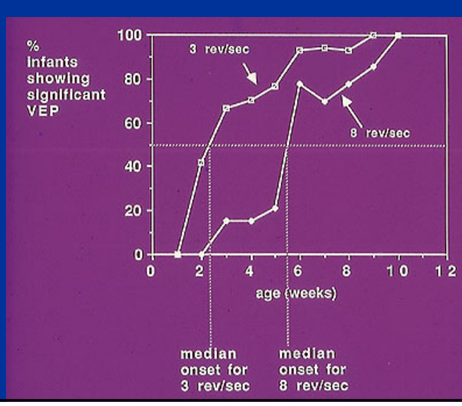


Orientation- and phase-reversal responses in the same infant, recordings one week apart

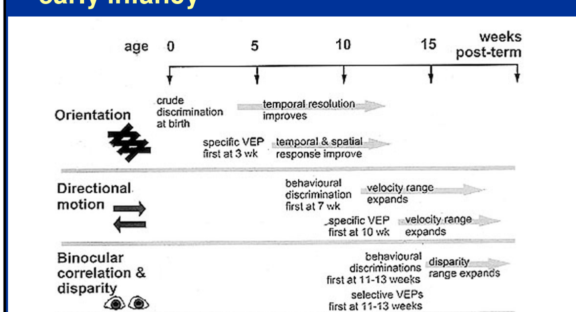


Braddick et al (1986)

Development of orientation-selective VEP



Development of cortical selectivity in early infancy



Note that different cortical functions all develop post-natally, but don't have a common age of onset

MOTION processing


motion processing – a pervasive aspect of vision


Volkmann & Dobson (1976) – 2 month infants preferential looking:

moving > static stimuli

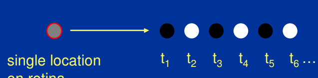
Does this mean that young infants process visual motion?

Consider:

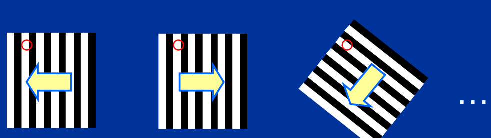
Infants also show high flicker sensitivity in preferential looking (Regal, 1981)

early stages of visual pathway (e.g. retinal ganglion cells) respond to temporal change but not to direction of motion

From flicker to direction of motion



is consistent with…



To determine direction of motion, need to compare

- across retinal locations (as for resolving orientation)

- and also across time

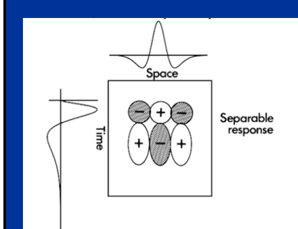


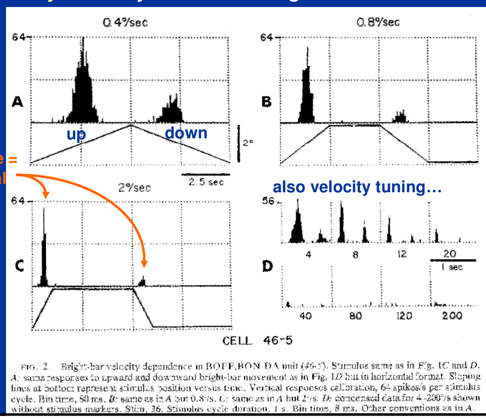
Fig. 6. A spatiotemporally separable impulse response. The spatial and temporal impulse responses are shown along the margins. Their product is shown schematically in the center. The spatiotemporal impulse re-sponse is a weighting function that sums inputs at various positions and times to determine the present output.

e.g. Adelson & Bergen 1985 - spatio-temporal receptive fields

Directionality – the key criterion in single-unit studies

Cat cortical cell

Difference = directional tuning

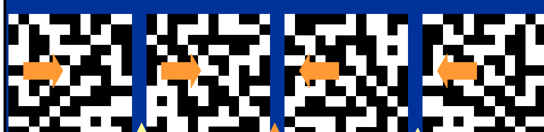


Emerson & Gerstein 1977

Directional sensitivity in infants

- evoked potential approach
- preferential looking approach

Infant VEPs : direction-reversal sequence



random 'jump'

direction reversal & random 'jump'

random 'jump'

direction reversal & random 'jump'

Infant direction-reversal VEP (Wattam-Bell 1991)

8 peaks : jumps (non-direction

4 peaks direction reversal

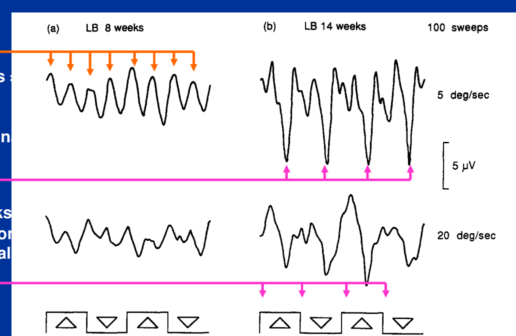


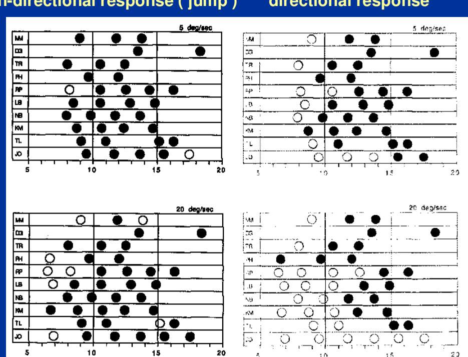
Fig. 4. (a) Motion VEPs from an 8 week old infant at 5 deg/sec (upper trace) and 20 deg/sec (lower trace). Stimulus alternation is given by the squarewave at the bottom. Sweep length 0.96 sec. (b) VEPs from the same infant at 14 weeks.

Infant direction-reversal VEP (Wattam-Bell 1991)

non-directional response ('jump') directional response

low speed (5 deg/sec

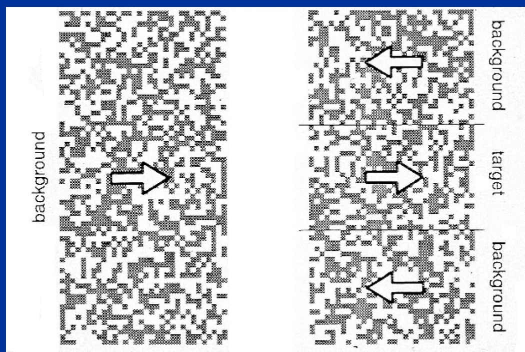
high speed (20 deg/sec



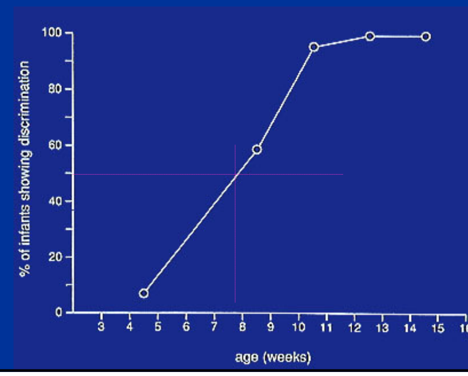
Infant direction-reversal VEP

- first seen about 10-11 weeks on average
- develops later for higher speeds
- direct comparison shows that it develops later than orientation-specific responses
(Braddick et al, 2005)

Preferential looking for directional motion

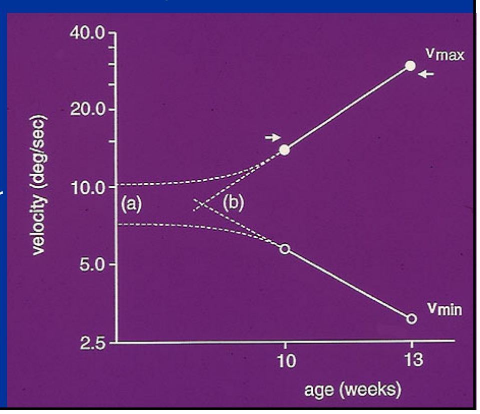


Preferential looking for directional motion



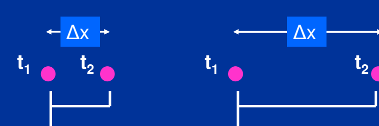
Preferential looking for directional motion

with age, sensitivity extends to both higher and lower speeds

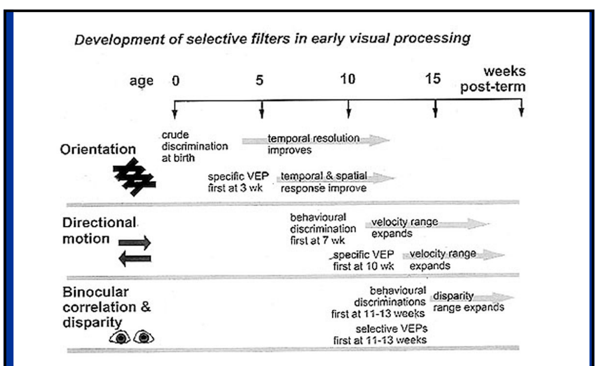


extension to higher velocities

- **higher velocities with age - primarily a spatial rather than temporal change**
- **a 'fine to coarse progression' (not expected from acuity changes)**



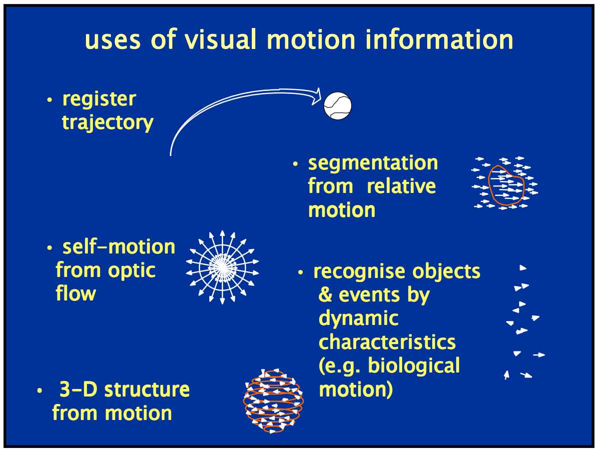
- **extension of horizontal connectivity in cortex?**
- **compare with extending disparity range for stereopsis**



All specific functions of primary visual cortex – but they don't have a common onset. Specific aspects of cortical connectivity each have to develop.

Plasticity of motion processing

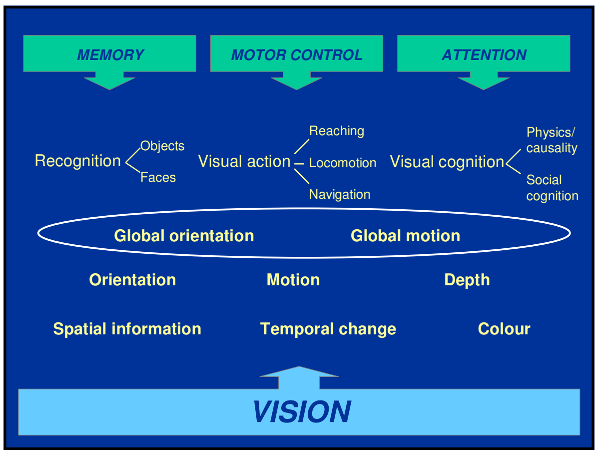
- **kittens reared in stroboscopic illumination – absence of directional cells in visual cortex** (Cynader, Berman & Hein, 1973; Pasternak et al, 1981)
- **kittens reared with directional bias show biased distribution of directional selectivity in cortical cells** (Daw & Wyatt, 1976)
- **separate periods of directional bias and monocular deprivation – show distinct critical periods for motion sensitivity (1st) and binocularity (2nd)** (Daw, Berman & Ariel, 1978)



Use of motion for perceptual tasks by 3-5 month-old infants

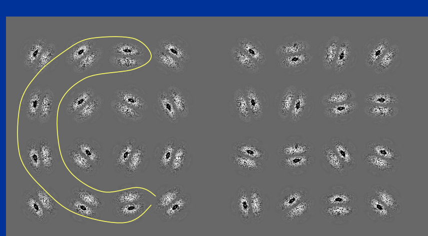
• 3-D structure from motion	Arterberry & Yonas (1988)
• distinguish rigid motion from non-rigid deformation	E J Gibson et al (1979)
• group parts of occluded object by common motion	Kellman & Spelke (1983)
• discriminate motion-defined forms	Kaufman-Hayoz et al (1986)
• discriminate biological motion	Berthenthal et al, 1985

…so directional information can be used for sophisticated perceptual analysis, soon after it first becomes available to the infant



GLOBAL form and motion processing

Coherent organization   Random organization

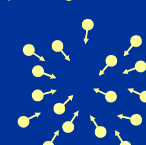


To perceive shapes, we need to look for useful changes in orientation over a large area – e.g. those indicating a **contour.**

Similarly with motion…

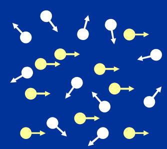
Expanding optic flow (moving forwards)

Contracting optic flow (moving backwards)



The same local motions are present in both cases, but the global organization is very different

To perceive global motion we need to integrate local motions over a large area



macaque V5/MT *(dorsal)*

response to coherence level of random dot motion

(Britten et al, *J Neurosci*, 1992; *Vis Neurosci*, 1993)

macaque V4 *(ventral)*

response to concentric or radial configurations

(Gallant Braun & Van Essen, *Science*, 1993):

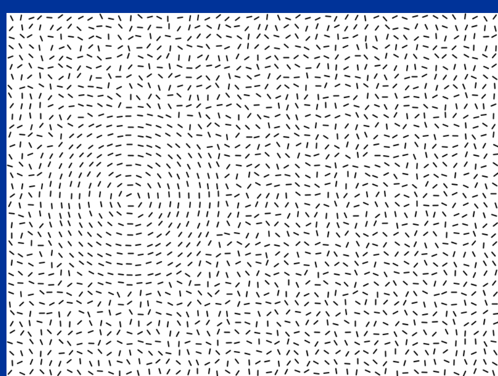
Measure of sensitivity to global form or motion: **coherence threshold**

What % of elements needs to be coherently organised in order for the global organisation to be perceived?

i.e.

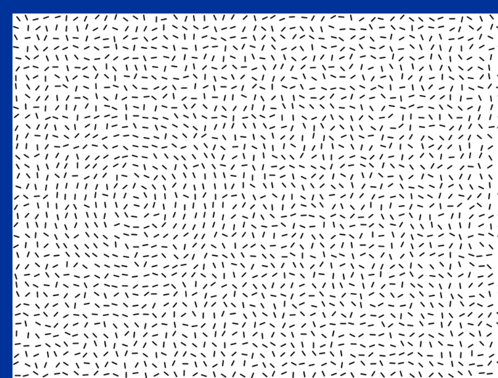
Lowest % at which global organisation is detected = observer's **coherence threshold**

Form coherence



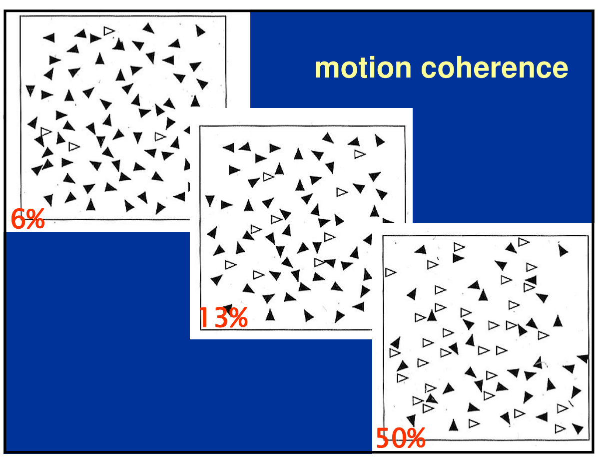
Coherence = 100%

Form coherence



coherence = 60%

motion coherence



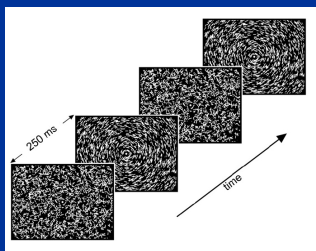
Development of global form and motion processing

Preferential looking and VEP measures:

- *Local* form emerges earlier than local motion
- Evidence for sensitivity to global motion and global form by 4-6 months (Braddick & Atkinson, 2007)
- Global form thresholds reach adult levels *later* than global motion (Gunn et al, 2002)

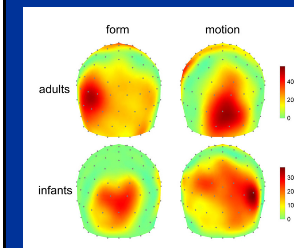
Extra-striate visual areas in development of global form and motion processing

Wattam-Bell et al (2010) – high density ERP recording with global form and motion stimuli in 5-month-olds and adults



Form stimulus.

Motion stimulus is identical, except that line segments represent motion of dots



Wattam-Bell et al (2010)

Like adults, infants show distinct patterns of activity for global form vs. motion

However, topography of responses is very different for infants and adults

Implies major re-organization of extra-striate visual processing in development.

Global motion from V5 in infants, but dominated by V3/V3A and V6 in adults?

SUMMARY:

Visual functions

MEMORY — *MOTOR CONTROL* — *ATTENTION*

Recognition: Objects, Faces

Visual action: Reaching, Locomotion, Navigation

Visual cognition: Physics/ causality, Social cognition

Global orientation **Global motion**

Orientation **Motion** **Depth**

Spatial information **Temporal change** **Colour**

VISION

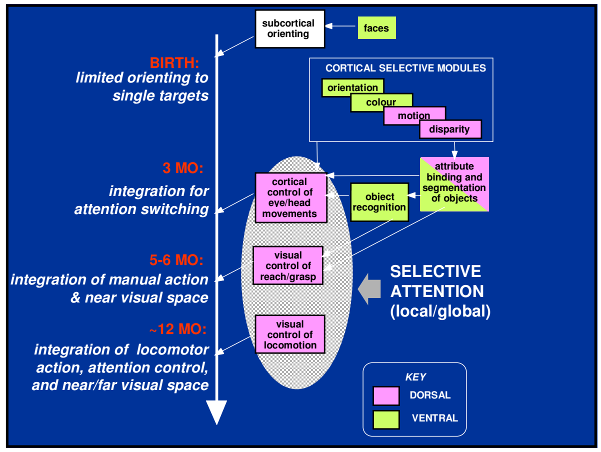
SUMMARY:

Research methods

- Forced-choice preferential looking
- Visual evoked potentials (VEP), aka Event-related potentials (ERP)

MODEL

- Atkinson & Braddick



END

Reading list (p. 1 of 4)

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Braddick, O, Birtles, D, Wattam-Bell, J & Atkinson, J (2005). Motion- and orientation-specific cortical responses in infancy. *Vision Research* 45: 3169-3179.

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