John Stein, Magdalen College,
Oxford University, UK

The neural basis of the phonological deficit in developmental dyslexia

Supported by The Dyslexia Research Trust (www.dyslexic.org.uk), Dyers & Colourists, Esmee Fairbairn, Norman Collisson, Garfield Weston and Wellcome Trusts, BBC Children in Need

Backward Reading

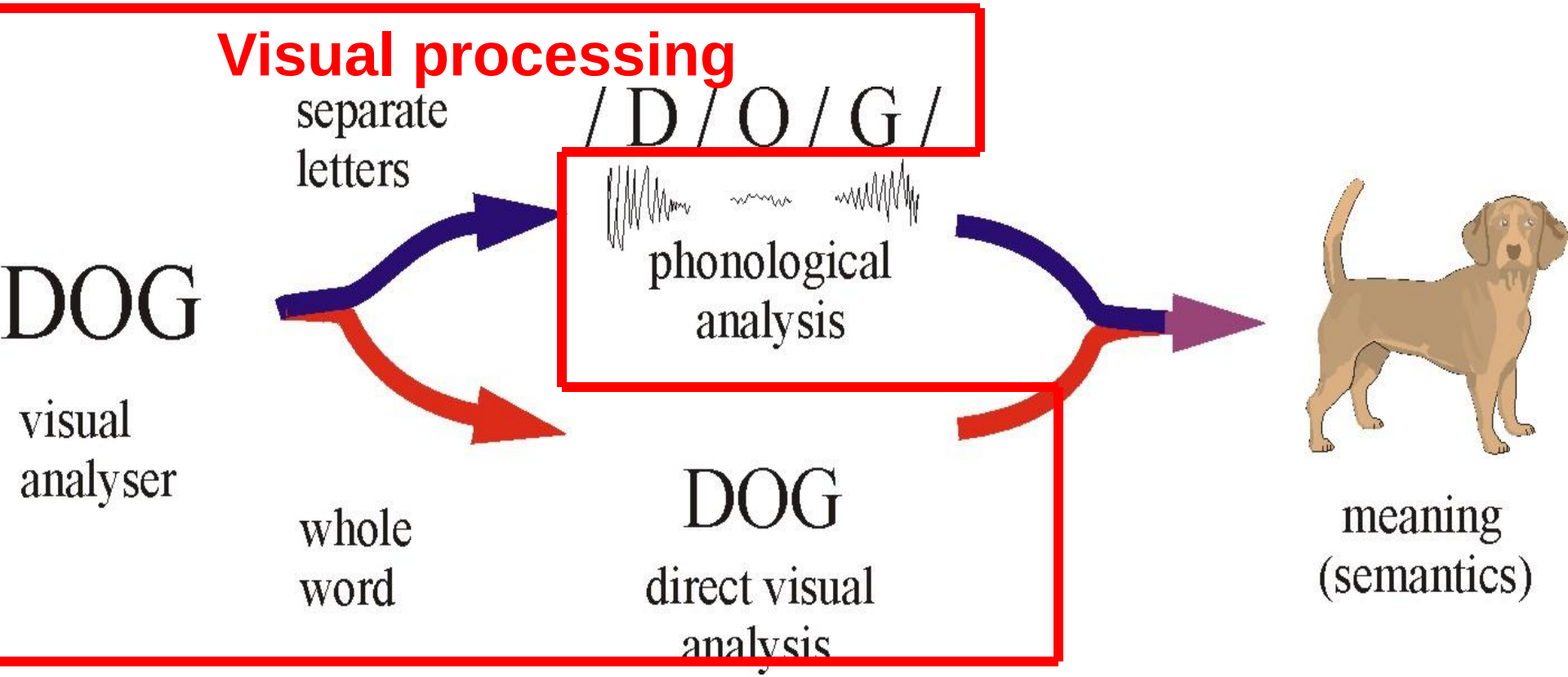
- 30% of school leavers cannot read better than an eleven year old
- 75% of young offenders in the UK are illiterate
- Whether or not we call these ‘dyslexic’, the same teaching methods will help any poor reader
- Developmental dyslexia: reading significantly below that expected from age and intelligence, despite good health, teaching and family support
- Dyslexia is more than a reading problem- the brain is different - a neurological syndrome
- Genetic, immunological, nutritional
- Slower processing, inattention, poor sequencing in all domains, poor short term memory, incoordination
- ? caused by impaired development of ‘magnocellular’ timing neurones

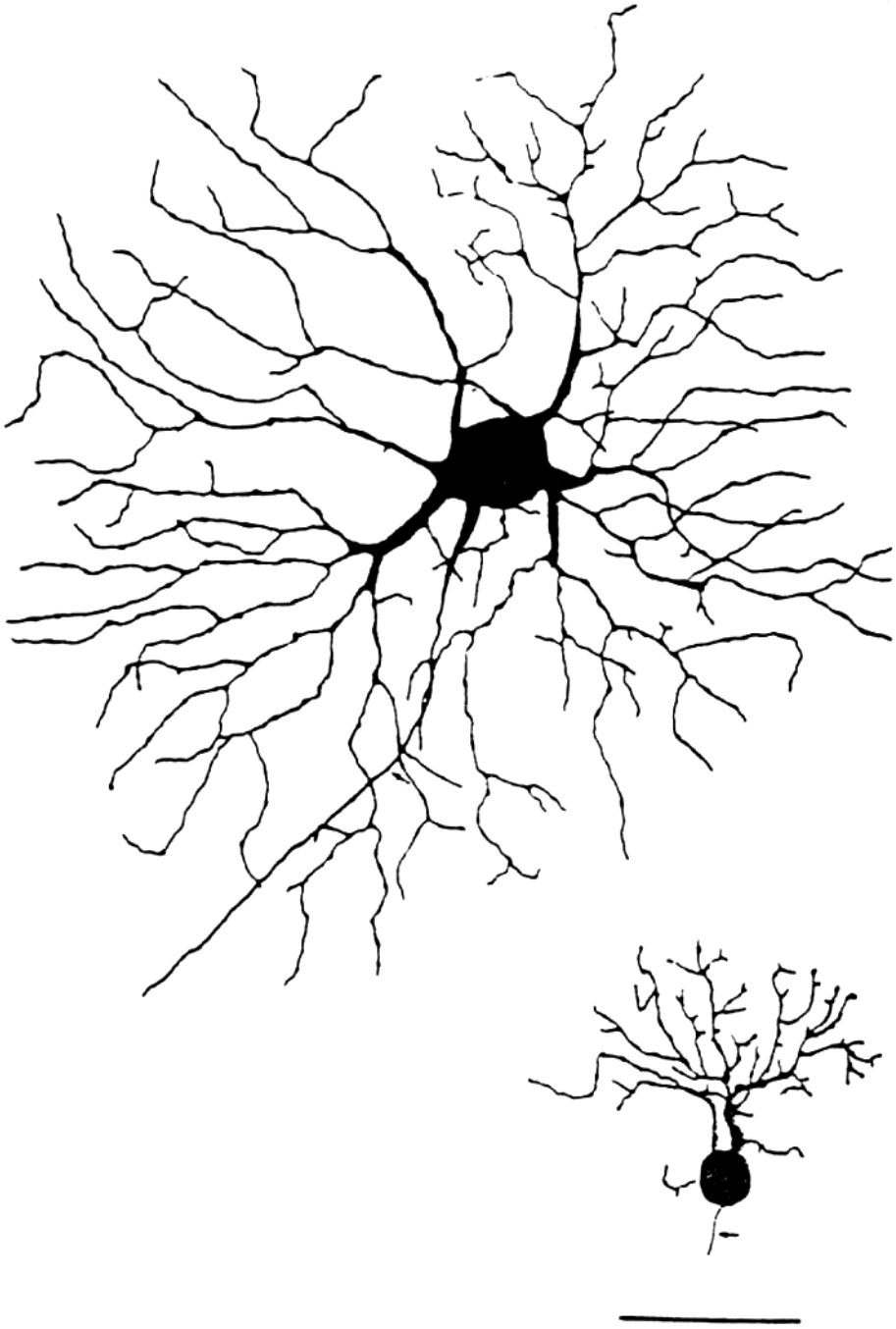
Many Dyslexics Experience **Visual** Confusions When Reading

- Letters reverse, blur, move across, in and out of page, change places, superimpose, distort, change colour
- At age 8 still getting letters and figures backwards & in wrong order
- **Spelling** remains very bad even into adulthood
- Poor visual **attention**
- Short visual **memory**
- Loses place easily
- ‘Careless’ mistakes
- Dreadful handwriting
- Mixes up capitals with lower case letters
- Glare - visual discomfort

“We were shattered to learn he was dyslexic. We thought he was learning Bulgarian.”

Reading is primarily a visual process



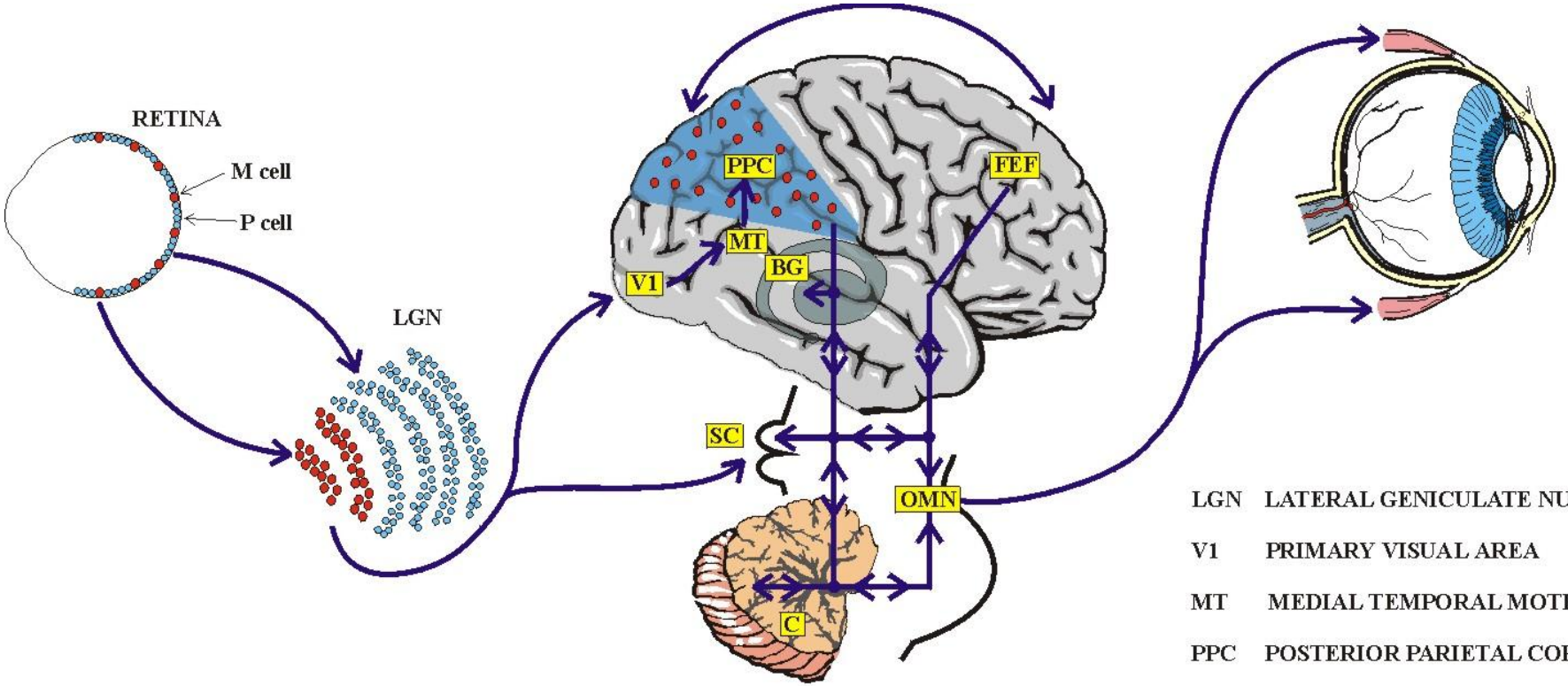


Retinal Ganglion cells

10% are large **magnocellular** cells (100x p- cells in area) - for timing visual events: fast responses, high contrast sensitivity, motion, flicker, control attention & eye movements

Most retinal ganglion cells are parvocellular (small): for colour, fine detail, high contrast (less vulnerable)

Visual magnocellular system dominates dorsal visuomotor pathway -directs visual attention & eye movements.



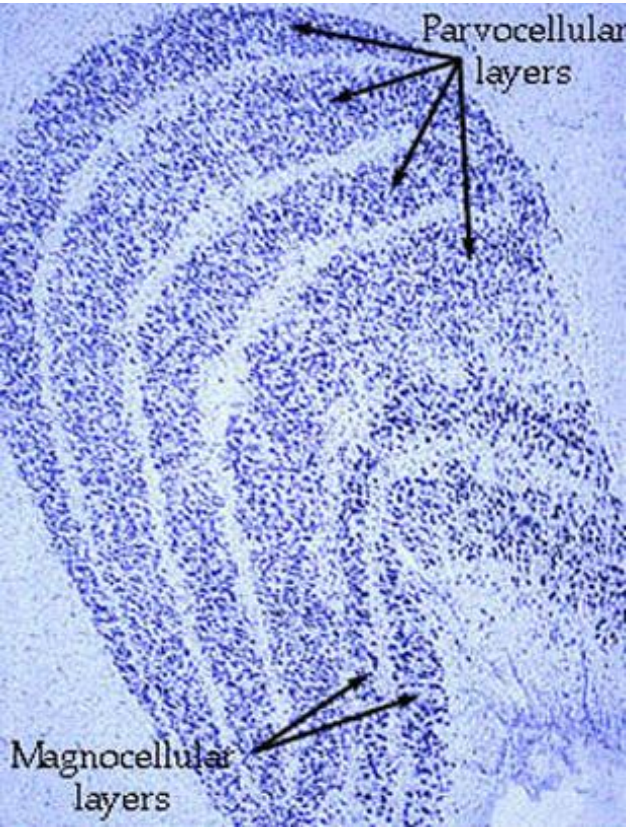
LGN	LATERAL GENICULATE NUCLEUS
V1	PRIMARY VISUAL AREA
MT	MEDIAL TEMPORAL MOTION AREA
PPC	POSTERIOR PARIETAL CORTEX
FEF	FRONTAL EYE FIELDS
BG	BASAL GANGLIA
SC	SUPERIOR COLLICULUS
C	CEREBELLUM
OMN	OCULAR MOTOR NUCLEI

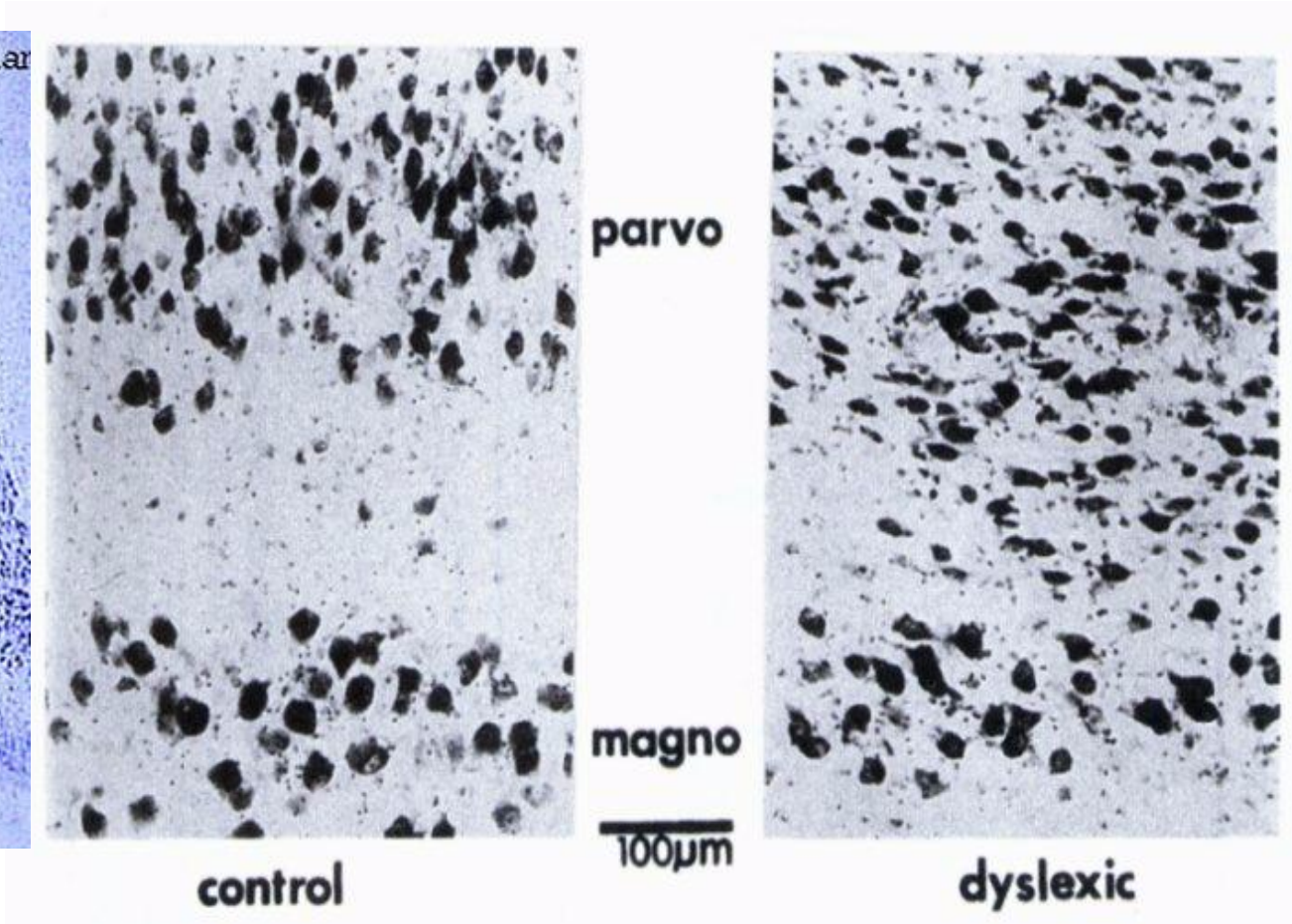
The visual magnocellular system is impaired in poor readers

- **30% smaller LGN magnocells *post mortem***
- **Reduced and delayed evoked brain waves**
- **Unstable eye control**
- Reduced visual motion sensitivity
- Lower sensitivity to flicker
- Lower sensitivity to low spatial, high temporal frequency contrast gratings
- Reduced activation of cortical visual motion areas (FMRI)
- Lower stereoacuity
- Poor visual sequential attention - slower visual search

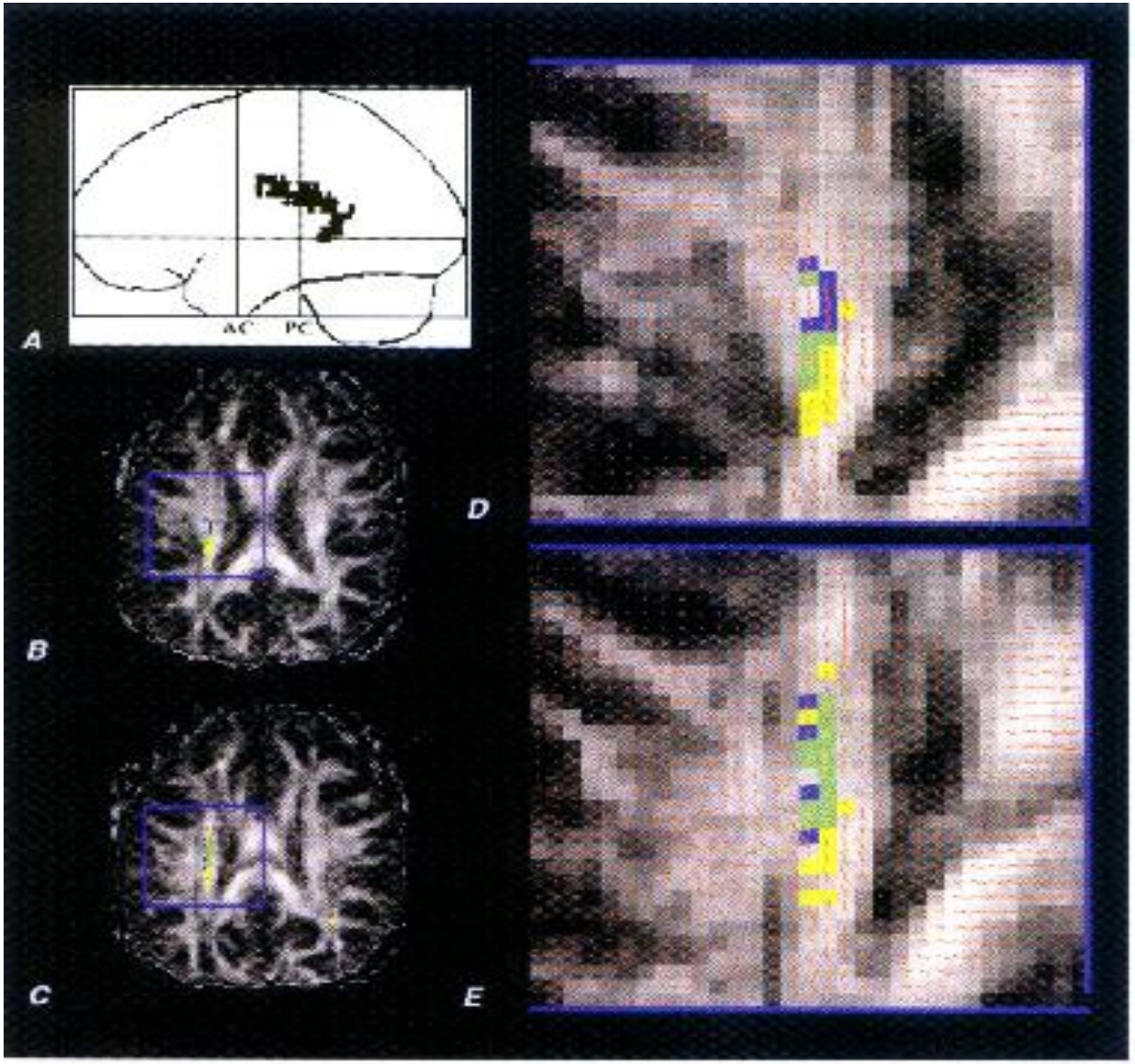
- In the last 10 years **90%** of new research papers have supported the magnocellular deficit theory
- But it is still controversial:
- Definition of magno- system - only completely separate in periphery
- Selectivity of stimuli
- Mild deficit requires highly sensitive test to reveal it

Abnormal magnocells in dyslexic visual relay - LGN

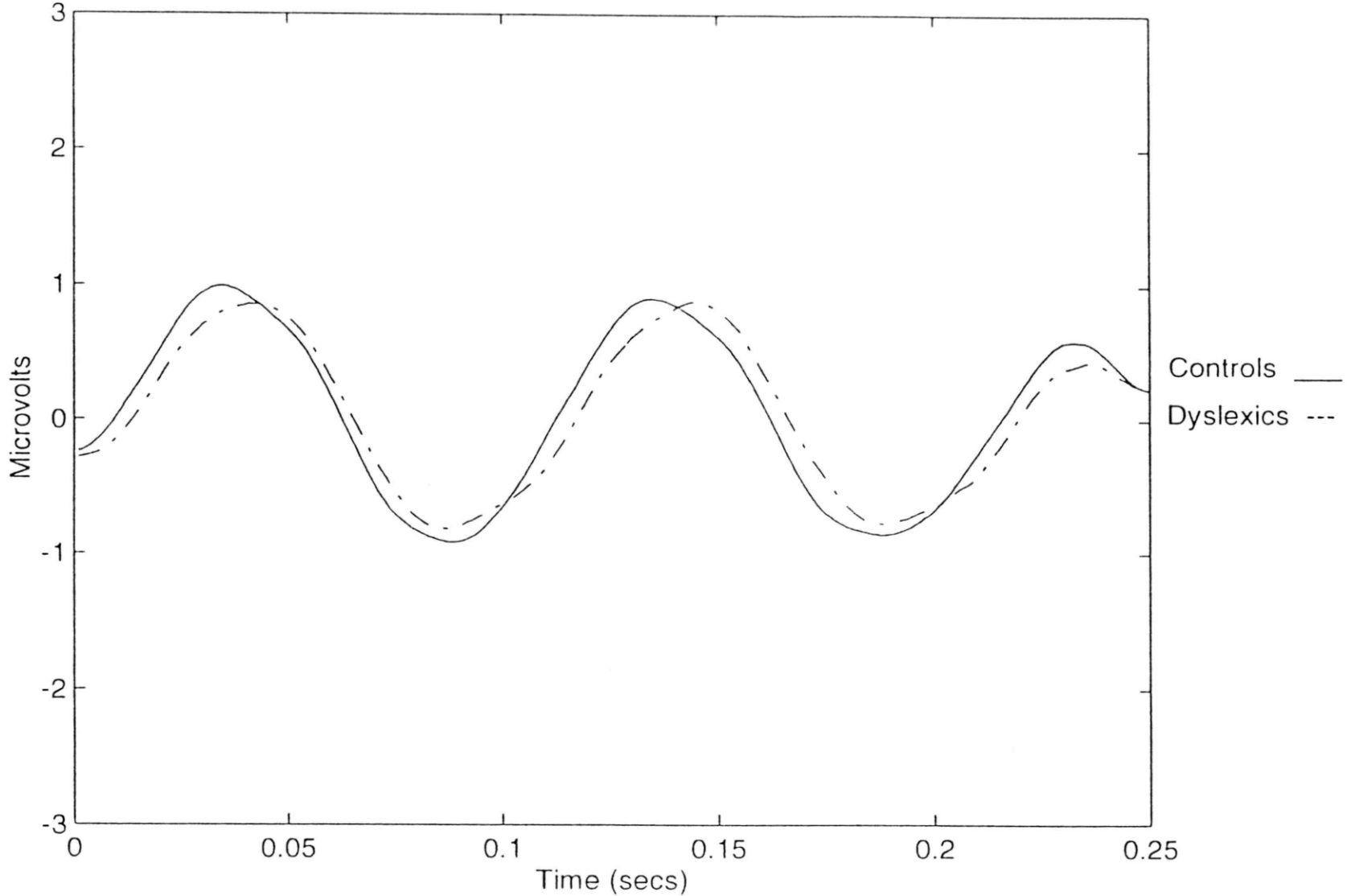




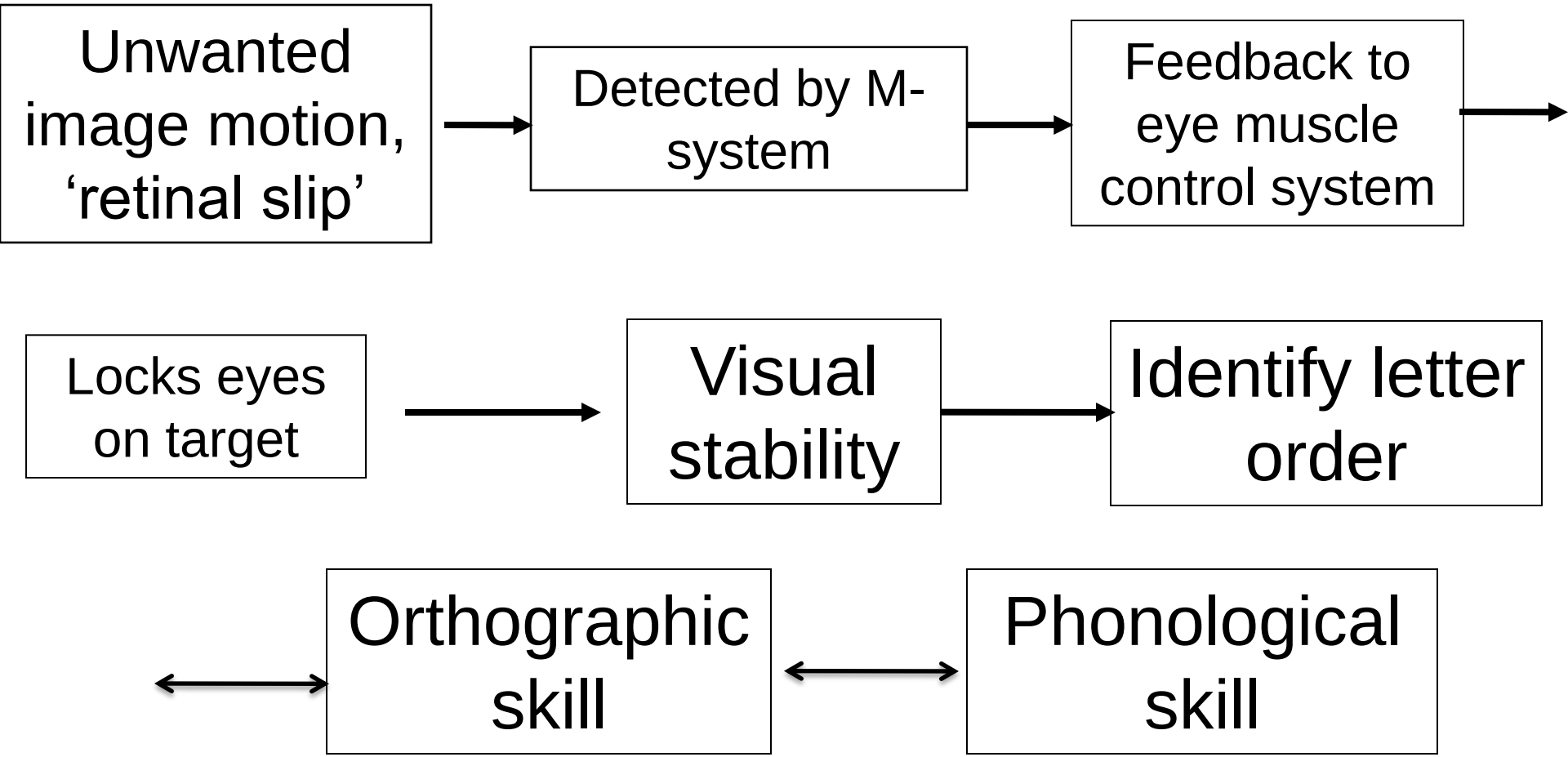
DTI - Fewer large axons in left angular gyrus in dyslexics. Successful remediation increases their size



Delayed Brain Potentials Evoked by Moving Visual Stimulus (10 hz component)



The visual magnocellular system stabilises the eyes to avoid visual wobble



Weak magnocellular system causes unstable vision - oscillopsia

"The letters go all blurry"

"The letters move over each other, so I can't tell which is which"

"The letters seem to float all over the page"

"The letters move in and out of the page"

"The letters split and go double"

"The c moved over the r, so it looked like another c"

"The p joined up with the c"

"d's and b's sort of get the wrong way round"

"The page goes all glary and hurts my eyes"

"I keep on losing my place"

Interventions that improve magno-function and eye control often improve reading

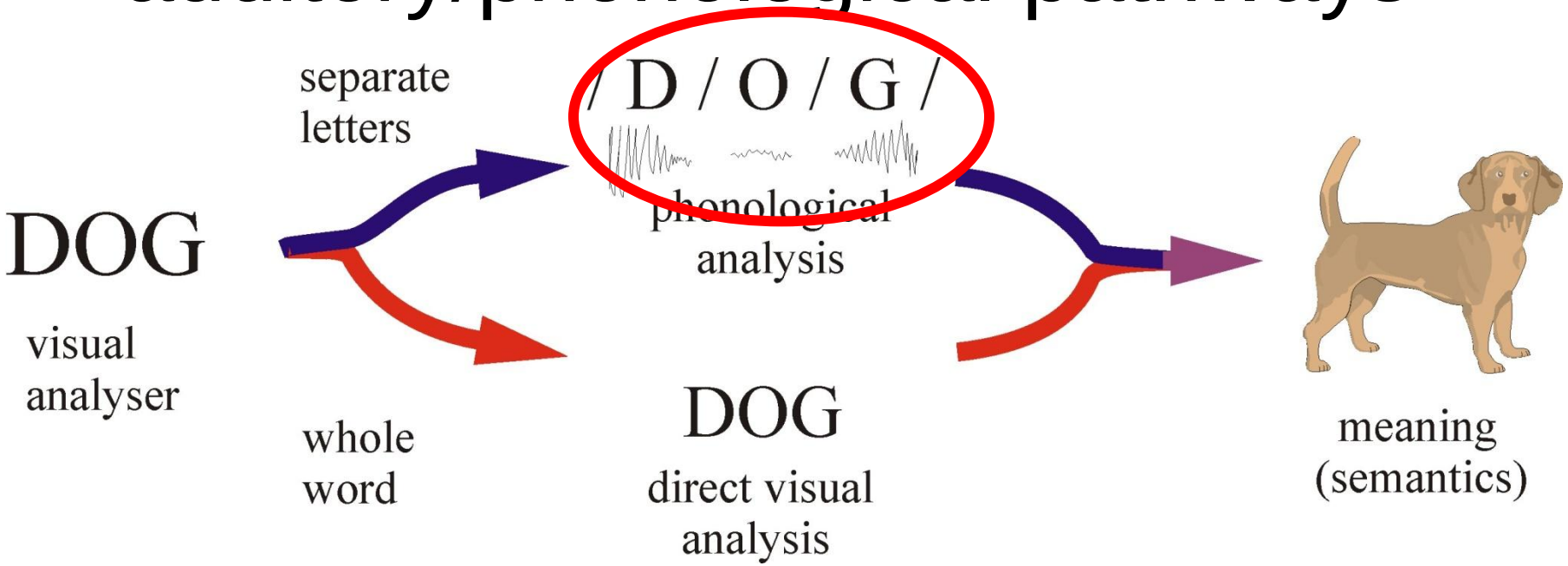
In half of all dyslexic children simply reading through deep blue or yellow filters can rebalance input to the visual M- system. Reading improves by av. 6 months in 3 months

In older children fixation exercises can stabilise binocular fixation and greatly improve reading

Auditory/phonological errors

- Whisk/wisp, deaf/death, effect/affect
- Ears (eves) dropping; sort (saute) of potatoes
- They came down on the food like a flock of vouchers
- The gossip spread like wild flies
- Concord is so noisy – too many decimals
- After a time I syphoned (deciphered) it
- Its just like flogging a brick wall
- I torned and tussed all night
- This strike will bring the country to a Stanstead
- Dry as a door nail; dead as rust; a soup opera
- Endearment (endowment) policy; customs and exile

The visual/orthographic and auditory/phonological pathways

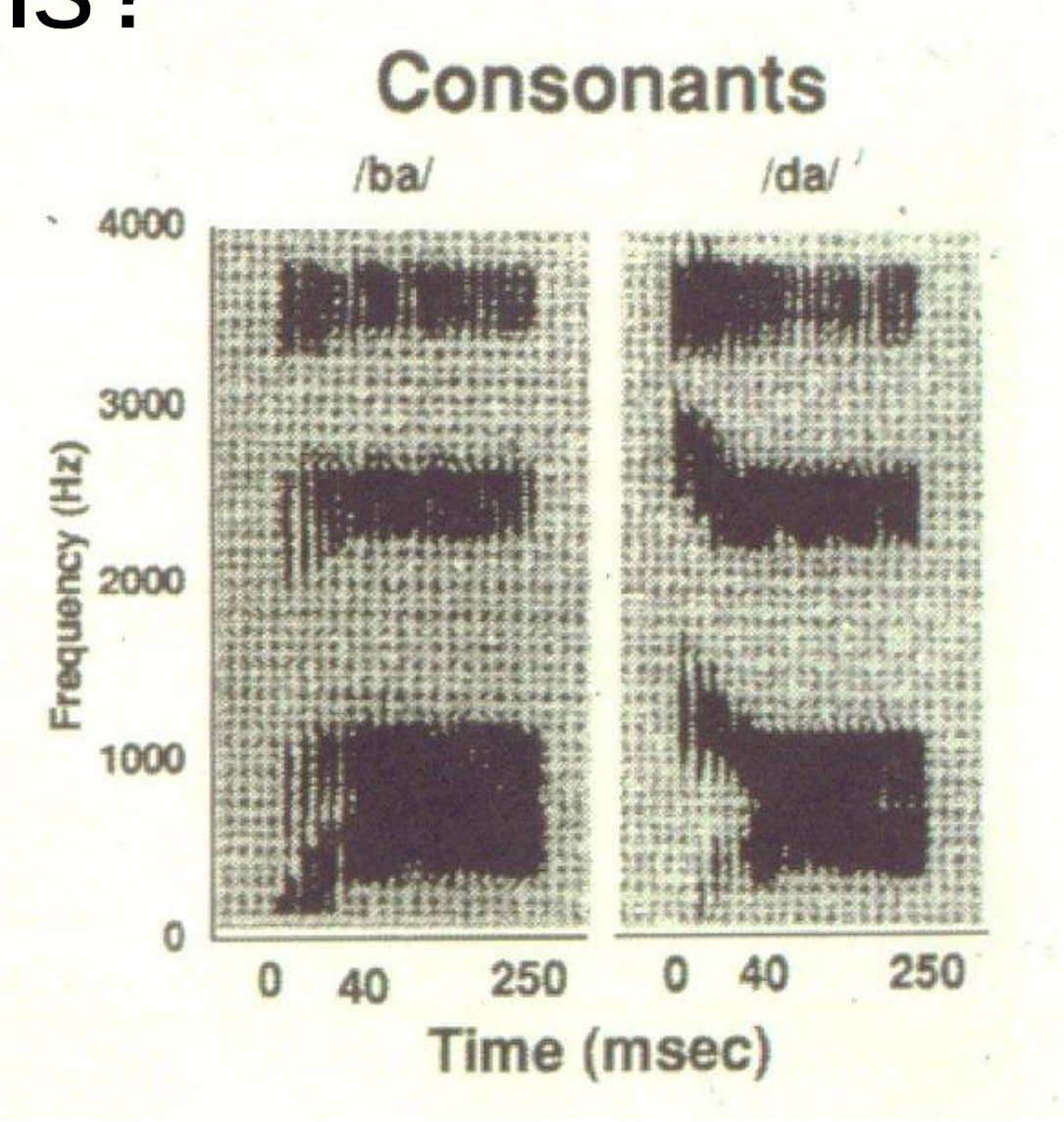


Auditory m-cells?

2nd and 3rd formants ascend in frequency for ‘b’;

but descend for ‘d’.

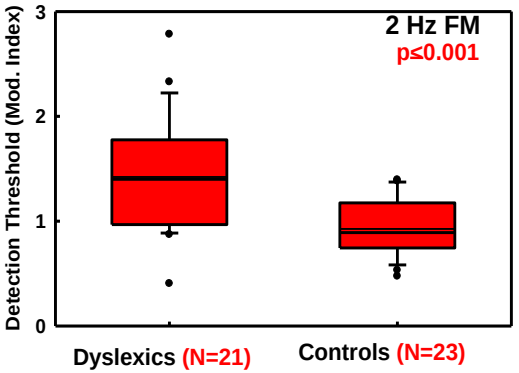
Auditory m- cell impairment may reduce sensitivity to these changes in sound frequency



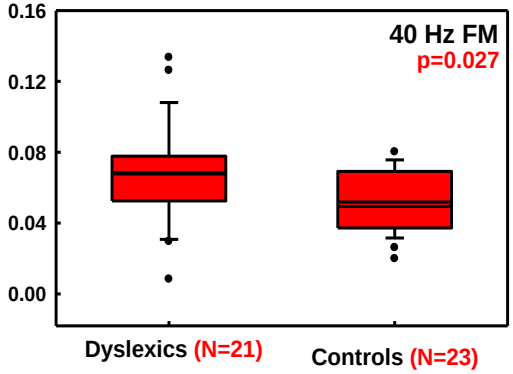
Developmental Dyslexics are less sensitive to changes in sound frequency and intensity.

- Slow frequency changes in speech are tracked in *real time* by large magnocells in the auditory system

2 Hz FM

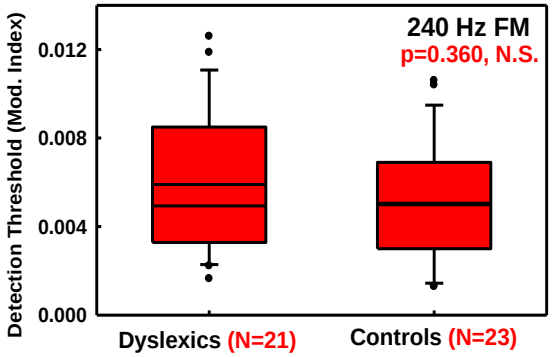


40 Hz FM



500 Hz pure tone

240 Hz FM



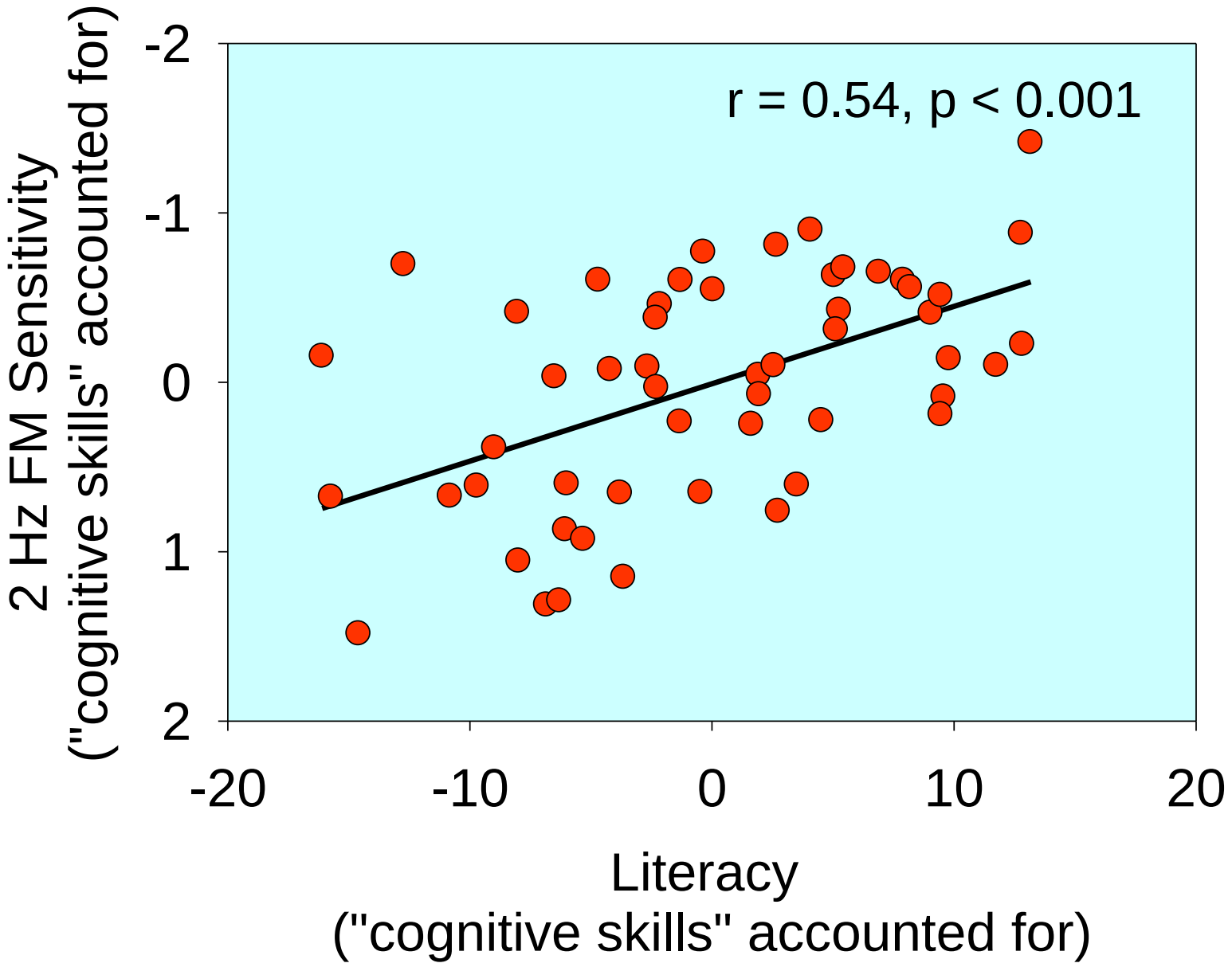
Witton, Talcott, Hansen, Richardson, Griffiths, Rees, Stein & Green, 1998

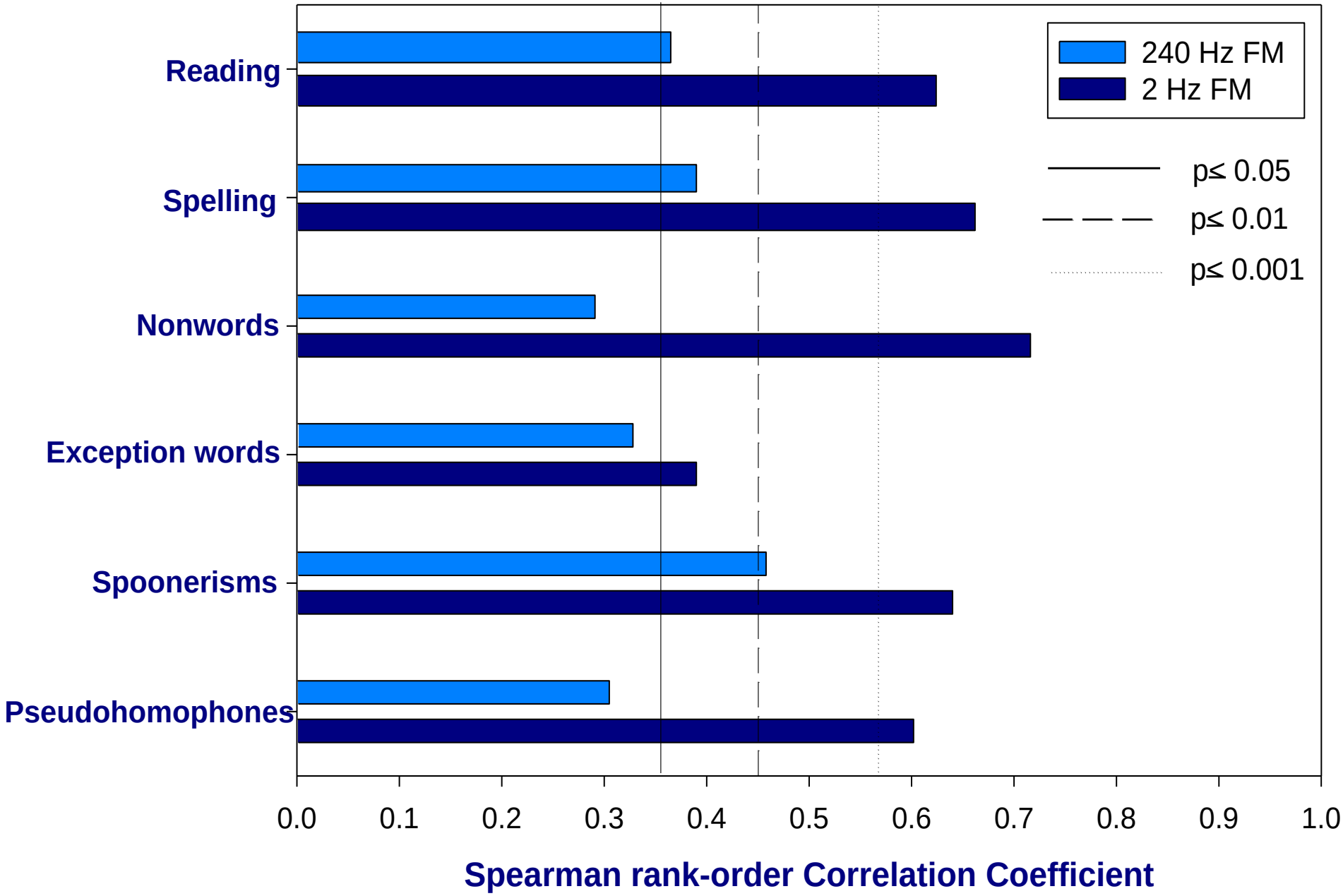
Nonsense Word Reading

Nonwords

‘tegwop’,‘blint’,‘plomt’,‘peltip’,‘visht’ can only be read if letters can be translated into their sounds quickly and accurately; hence they test **phonological** ability.

2 Hz FM Thresholds in 10 year-olds (n = 54)

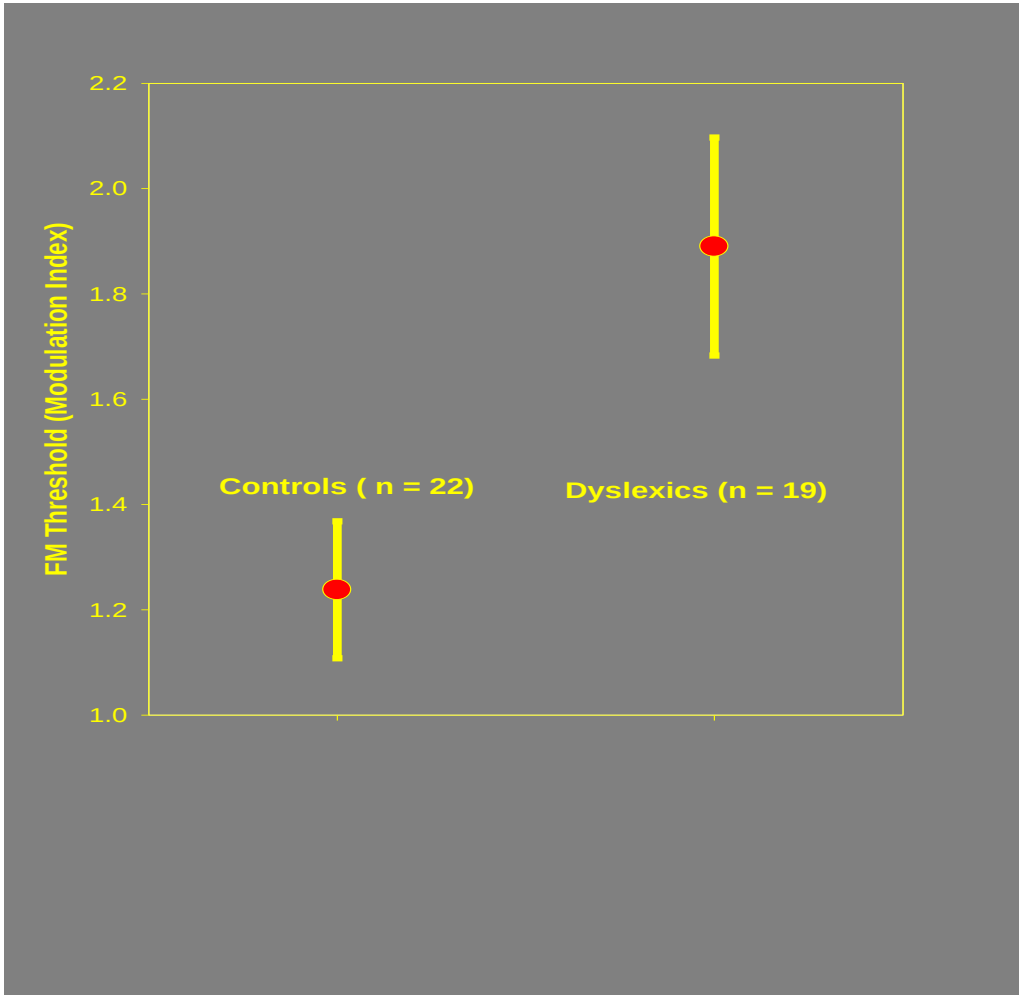



240 Hz FM
2 Hz FM
p≤ 0.05
p≤ 0.01
p≤ 0.001
Reading
Spelling
Nonwords
Exception words
Spoonerisms
Pseudohomophones
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Spearman rank-order Correlation Coefficient

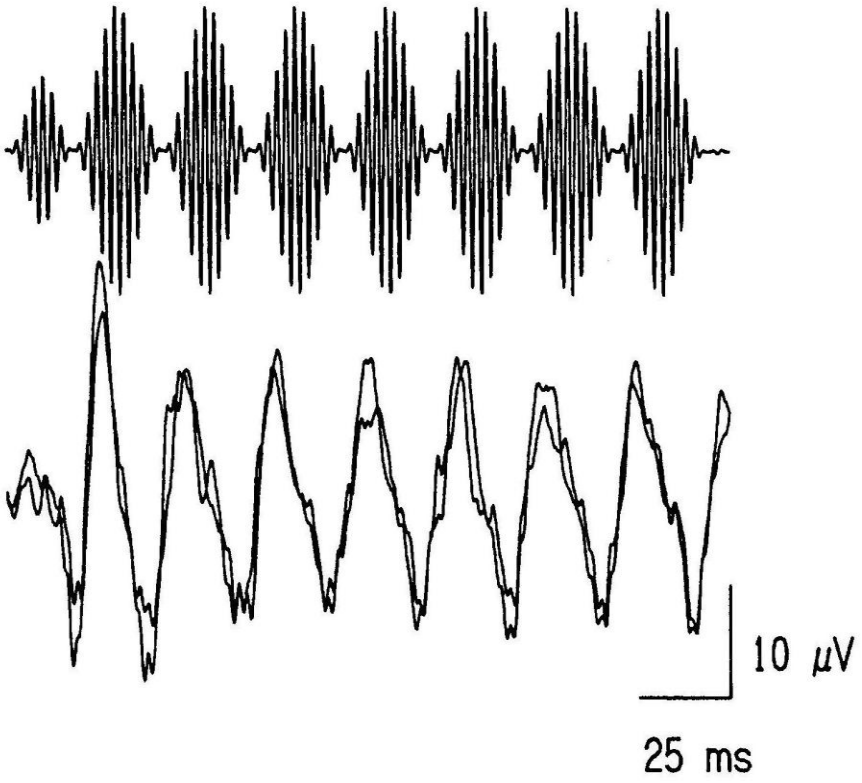
Norwegian 10 year olds

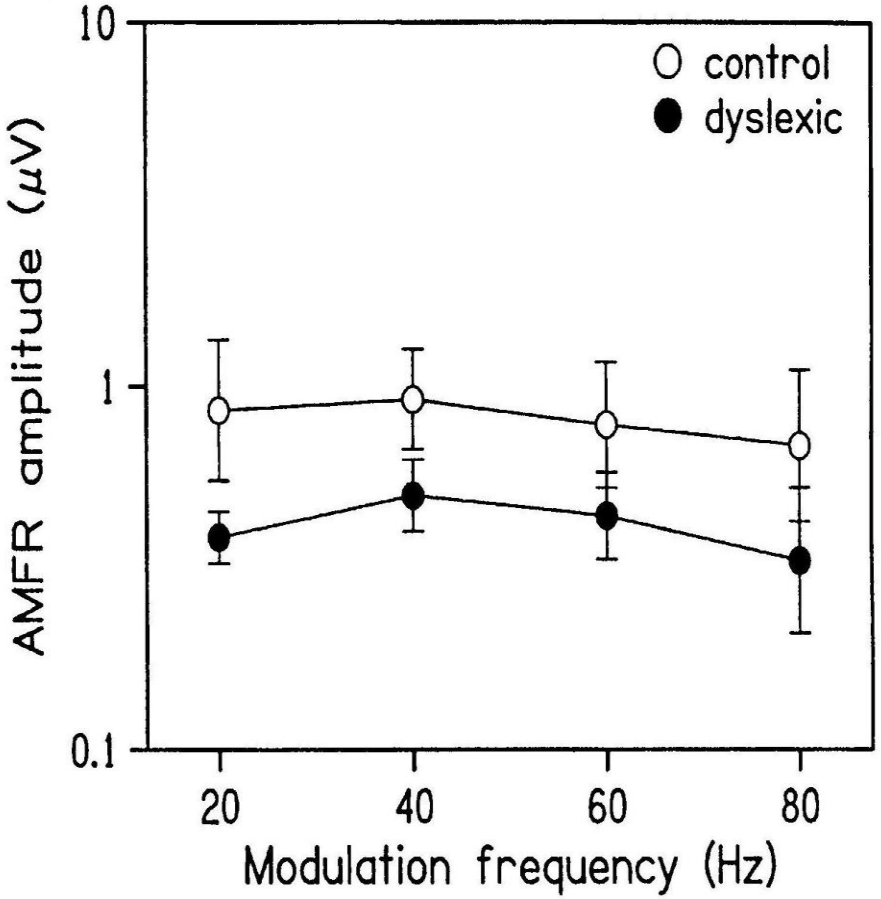
- Low sensitivity to auditory frequency change is found not only in English dyslexics, but also in more regular Norwegian

Auditory FM



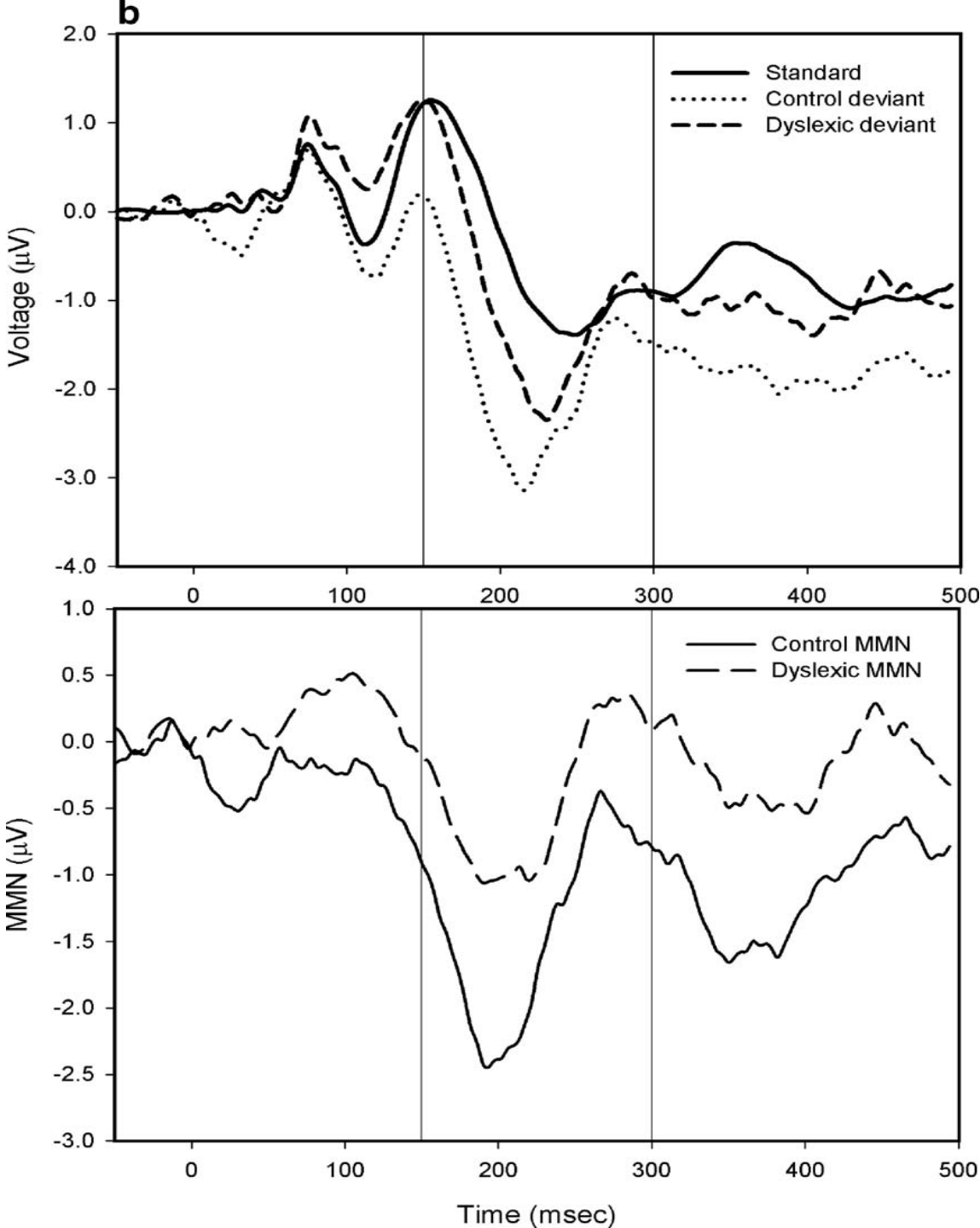
Auditory brainstem responses more sensitive (AM)



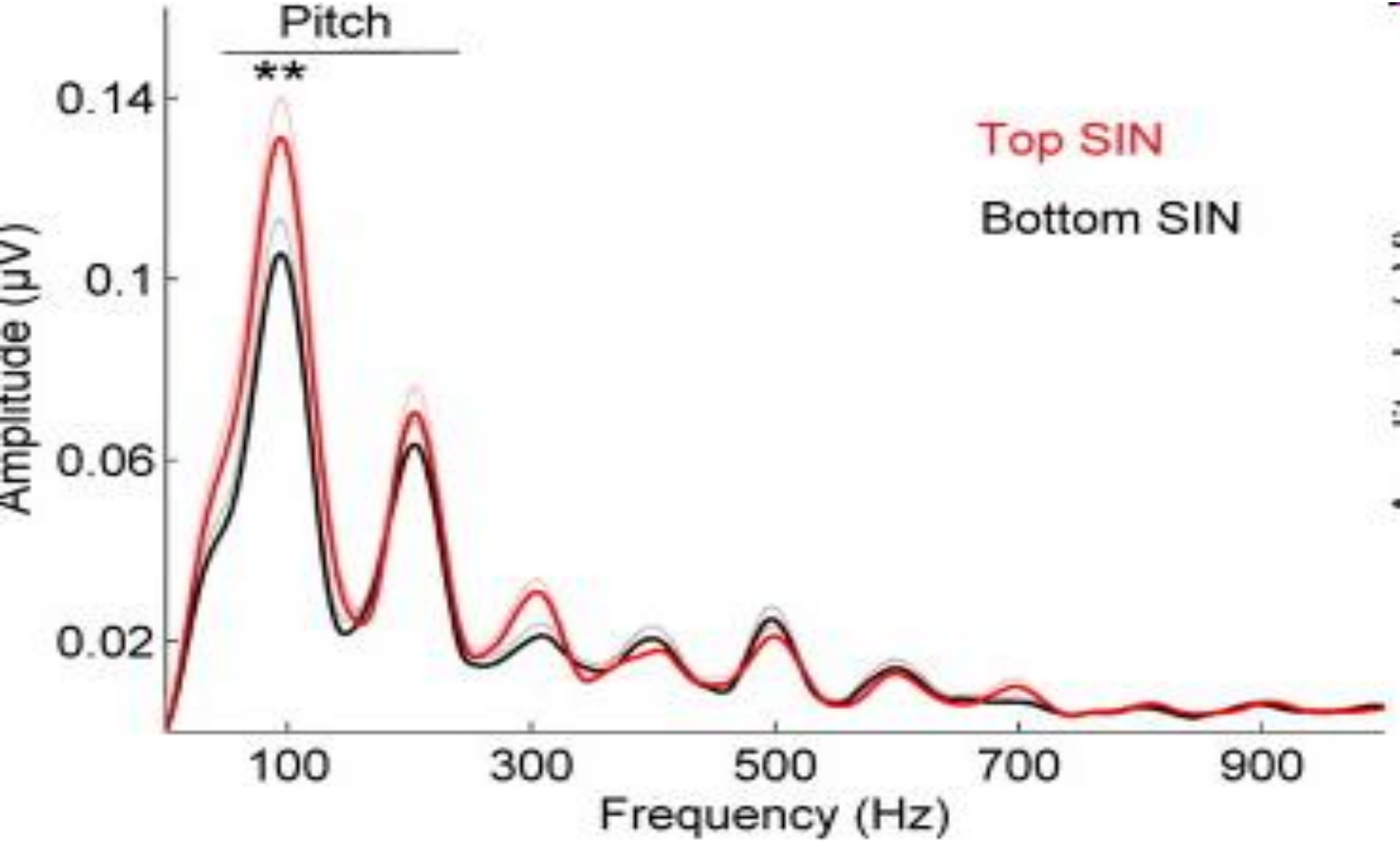


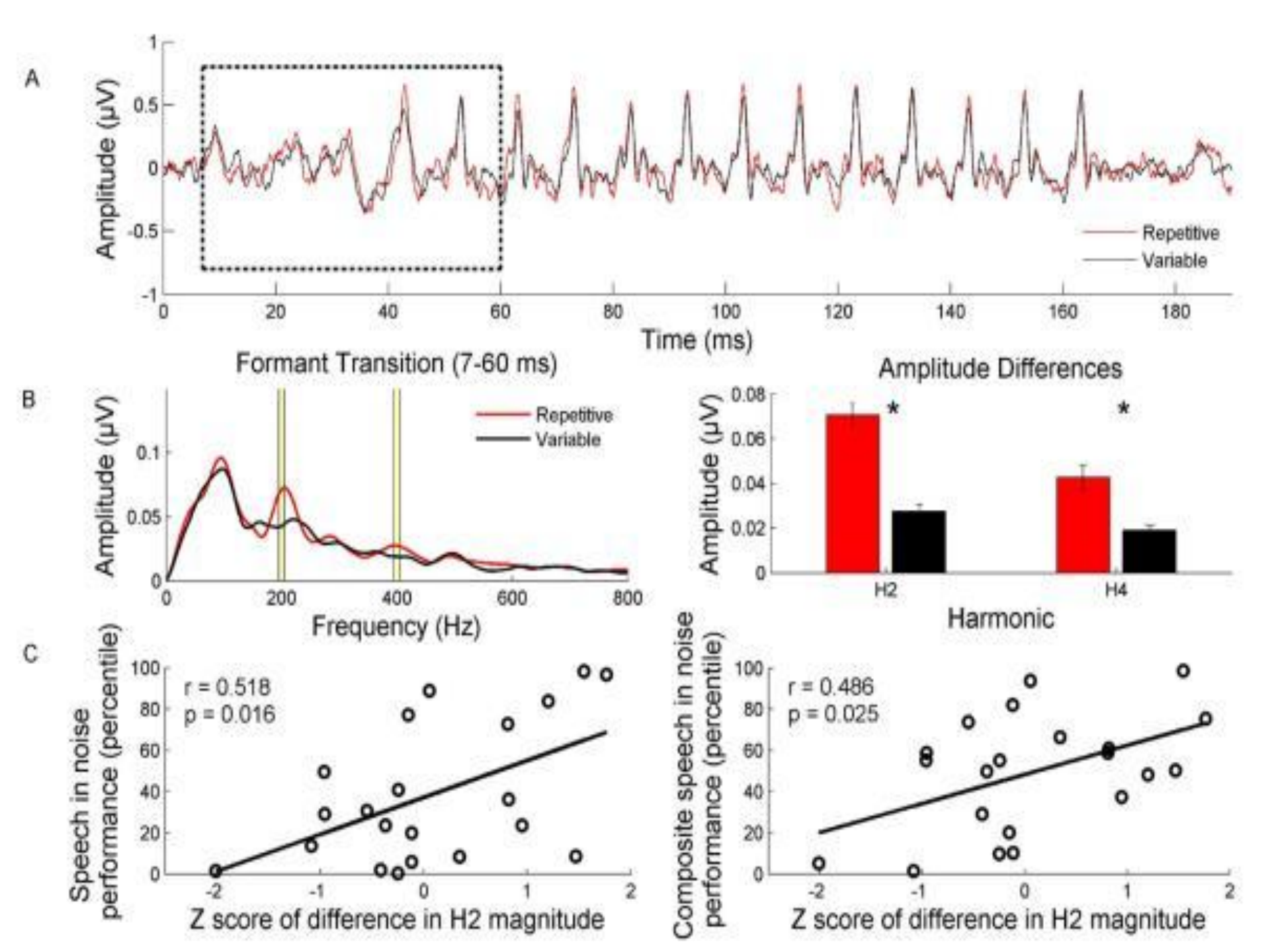
Psychophysical sensitivity to 20 Hz FM was normal in 10 adult dyslexics.

But their mismatch negativity was significantly decreased compared to normal readers.



Auditory Brainstem Responses (speech in noise)

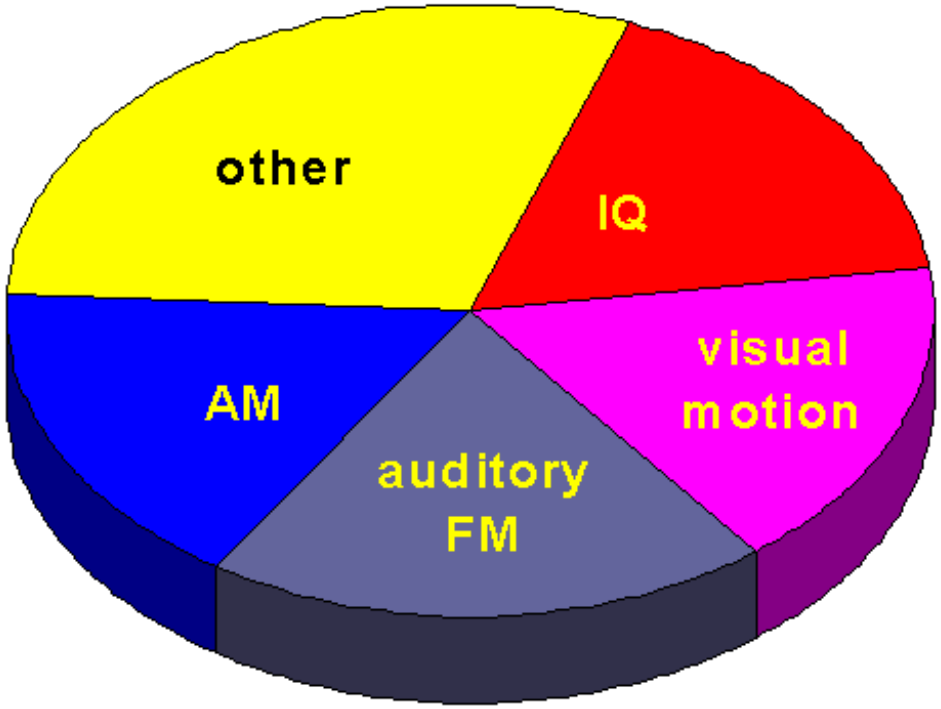



A
Amplitude (μV)
Time (ms)
Repetitive
Variable
B
Formant Transition (7-60 ms)
Amplitude (μV)
Frequency (Hz)
Repetitive
Variable
Amplitude Differences
Amplitude (μV)
H2
H4
Harmonic
C
Speech in noise performance (percentile)
r = 0.518
p = 0.016
Z score of difference in H2 magnitude
Composite speech in noise performance (percentile)
r = 0.486
p = 0.025
Z score of difference in H2 magnitude

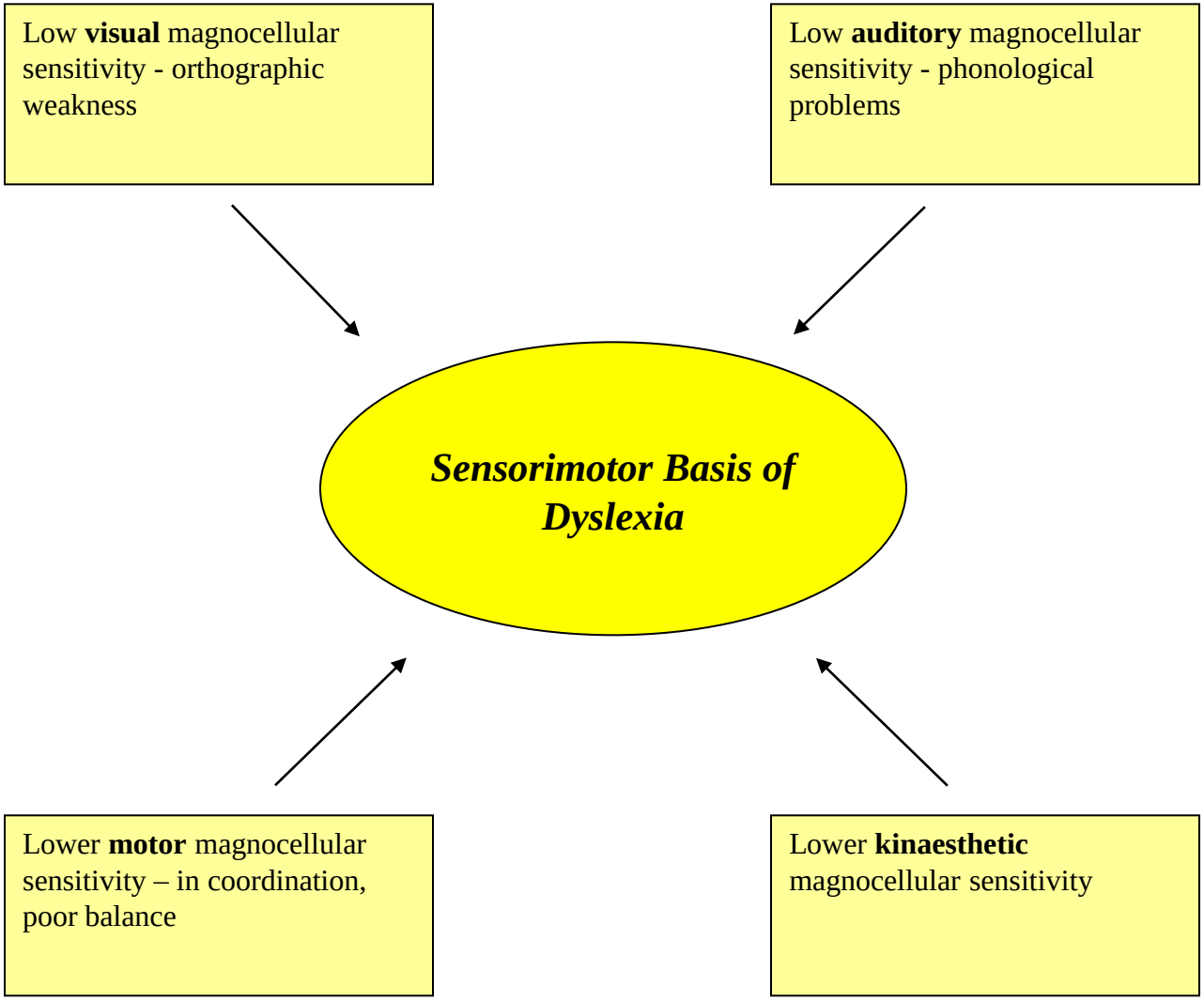
Is there an Auditory Magnocellular System?

- Large neurones in the auditory brainstem (DCN, ICX, mMGN) signal start, finish, changes in amplitude, frequency and phase of sounds.
- FM and AM sensitivity in both good and poor readers determines their phonological ability.
- Poor readers have:
  - reduced pure tone discrimination,
  - reduced AM & FM sensitivity,
  - smaller brainstem auditory evoked potentials (ABR)
  - smaller magnocellular neurones in MGN.
- Thus poor readers may have impaired development of their auditory magnocells

Auditory and visual magnocellular sensitivity determines over half of variability in children's phonological ability

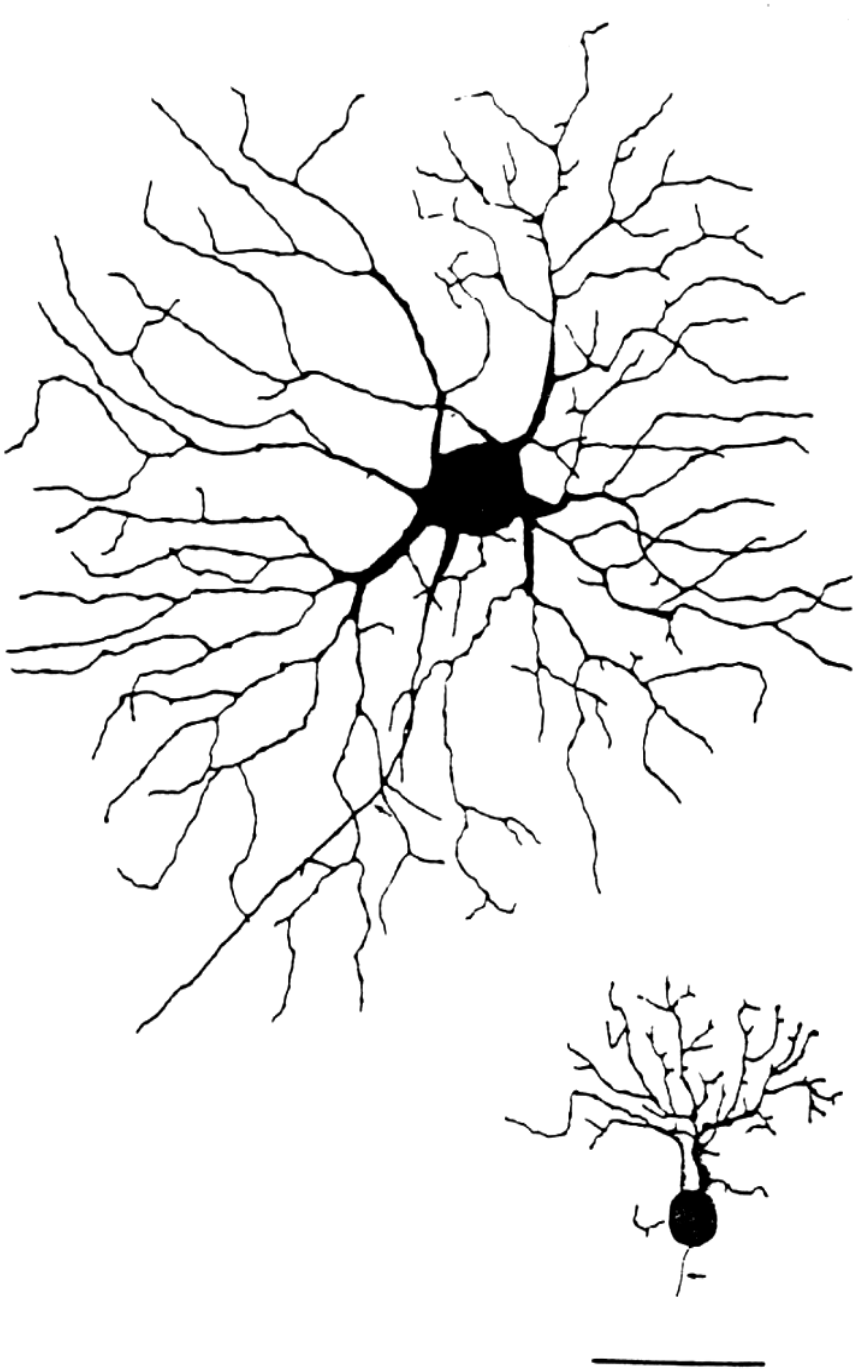


Thus the most important determinant of reading ability appears to be low level magnocellular sensitivity.
Encouraging because this can be improved by training


Low **visual** magnocellular sensitivity - orthographic weakness
Low **auditory** magnocellular sensitivity - phonological problems
Sensorimotor Basis of Dyslexia
Lower **motor** magnocellular sensitivity – in coordination, poor balance
Lower **kinaesthetic** magnocellular sensitivity

Magnocellular Neurones

- A system of large neurones specialised for temporal processing – tracking changes in light, sound, position etc. for direction of attention
- Large, fast conduction, fast transmission, high anisotropy
- All express same surface antigen, CAT 301
- Found throughout the whole brain: visual, auditory, skin, muscle proprioceptors, cerebral cortex, hippocampus, cerebellum, brainstem
- Very vulnerable. Impaired m- cell development has been found in prematurity, foetal alcohol syndrome, developmental dyslexia, dyspraxia, dysphasia, ADHD, ASD, Williams syndrome, schizophrenia, depression
- M- cell high dynamic sensitivity requires high membrane flexibility provided by local environment of essential fatty acids, particularly **omega 3s**, found in fish oils
- Hence vulnerable to omega-3 deficiency



What causes this general magnocellular impairment?

Genetic

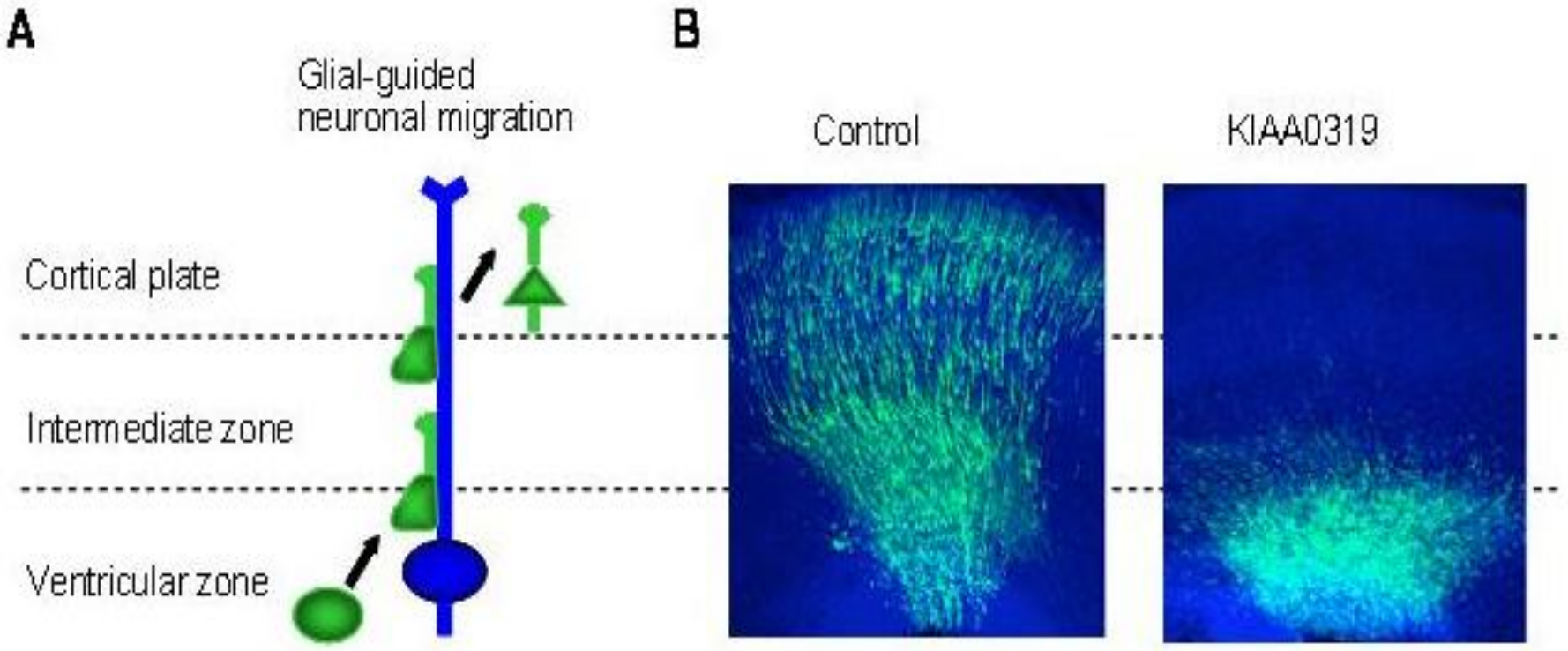
Immune System

Nutrition

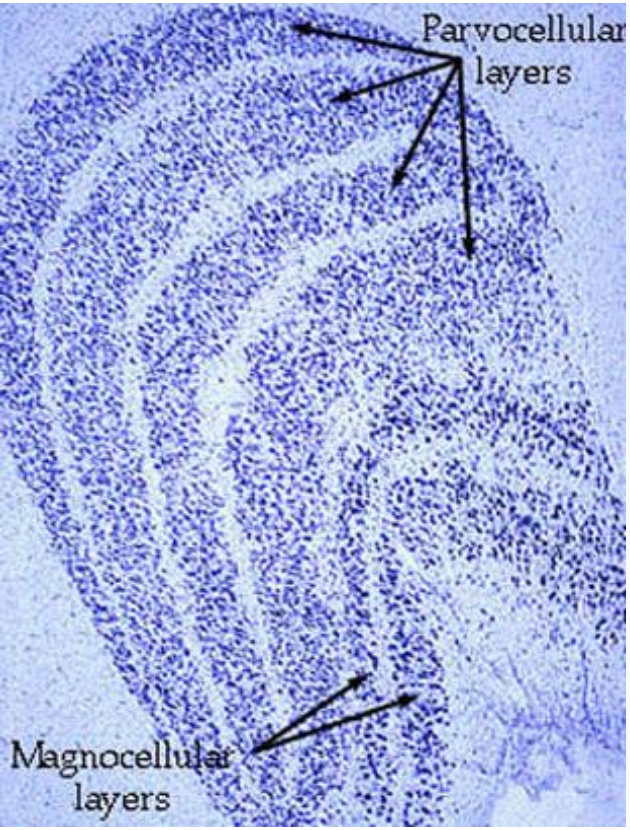
Genetic linkage/association

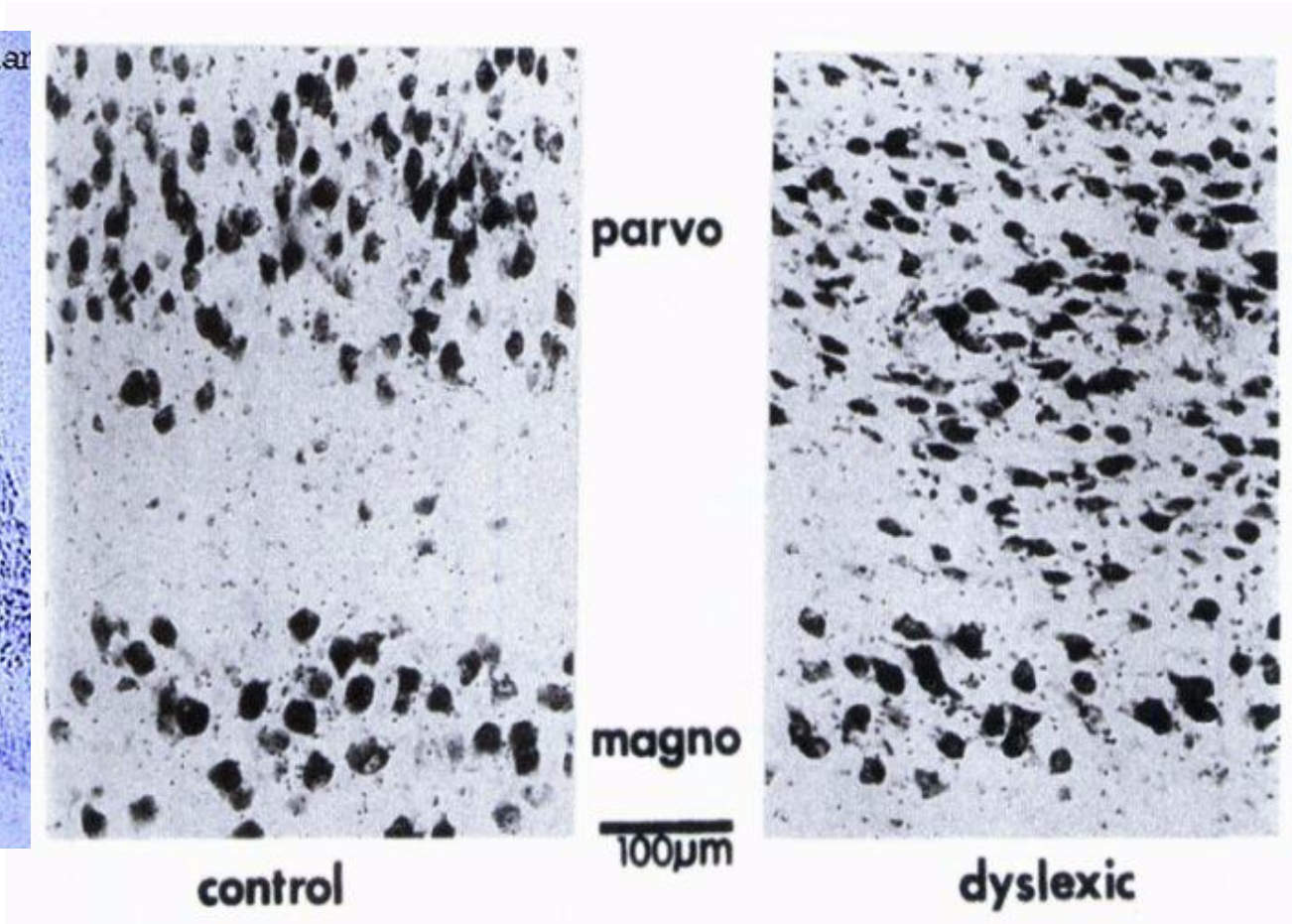
- Are particular chromosomal markers/sites associated with poor reading?
- Analyse the DNA of father, mother and their dyslexic and normally reading children
- >400 Oxford; 100 Boulder (US) families
- EU consortium; 1000 families, 2000 cases, 2000 controls, 50,000 markers per case

C6 KIAA 0319 controls neuronal migration during early brain development *in utero.* Downregulation in dyslexics may explain ectopias and other mismigrations of magnocellular neurones

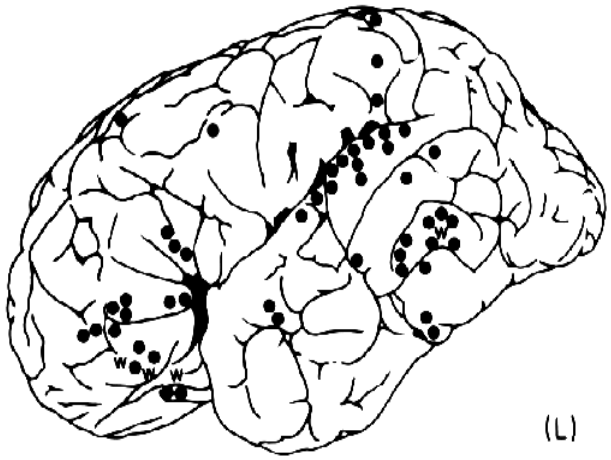


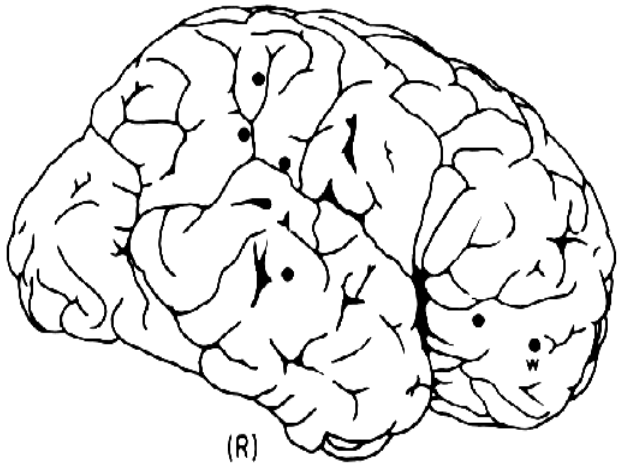
Abnormal magnocells in dyslexic visual relay - LGN

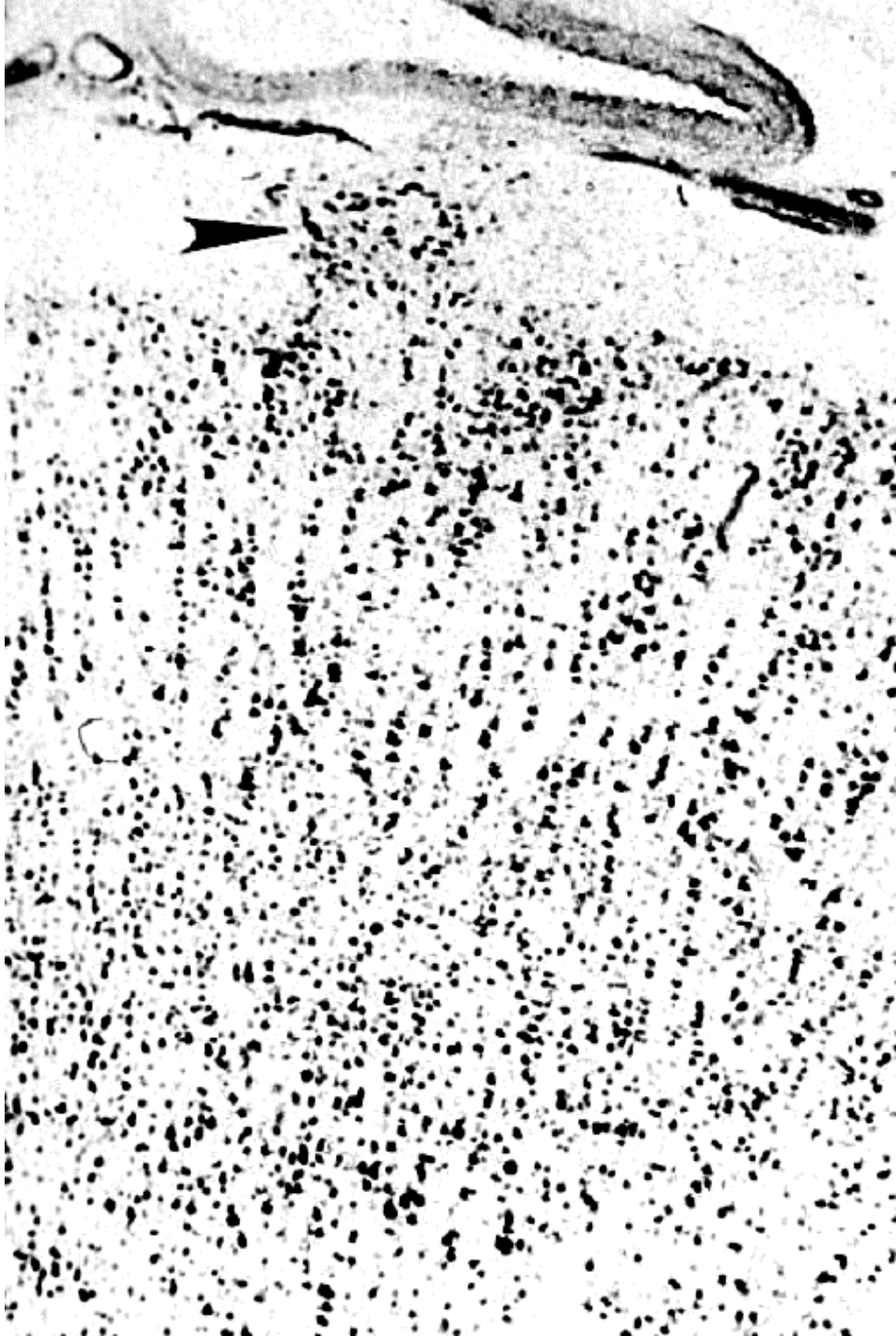


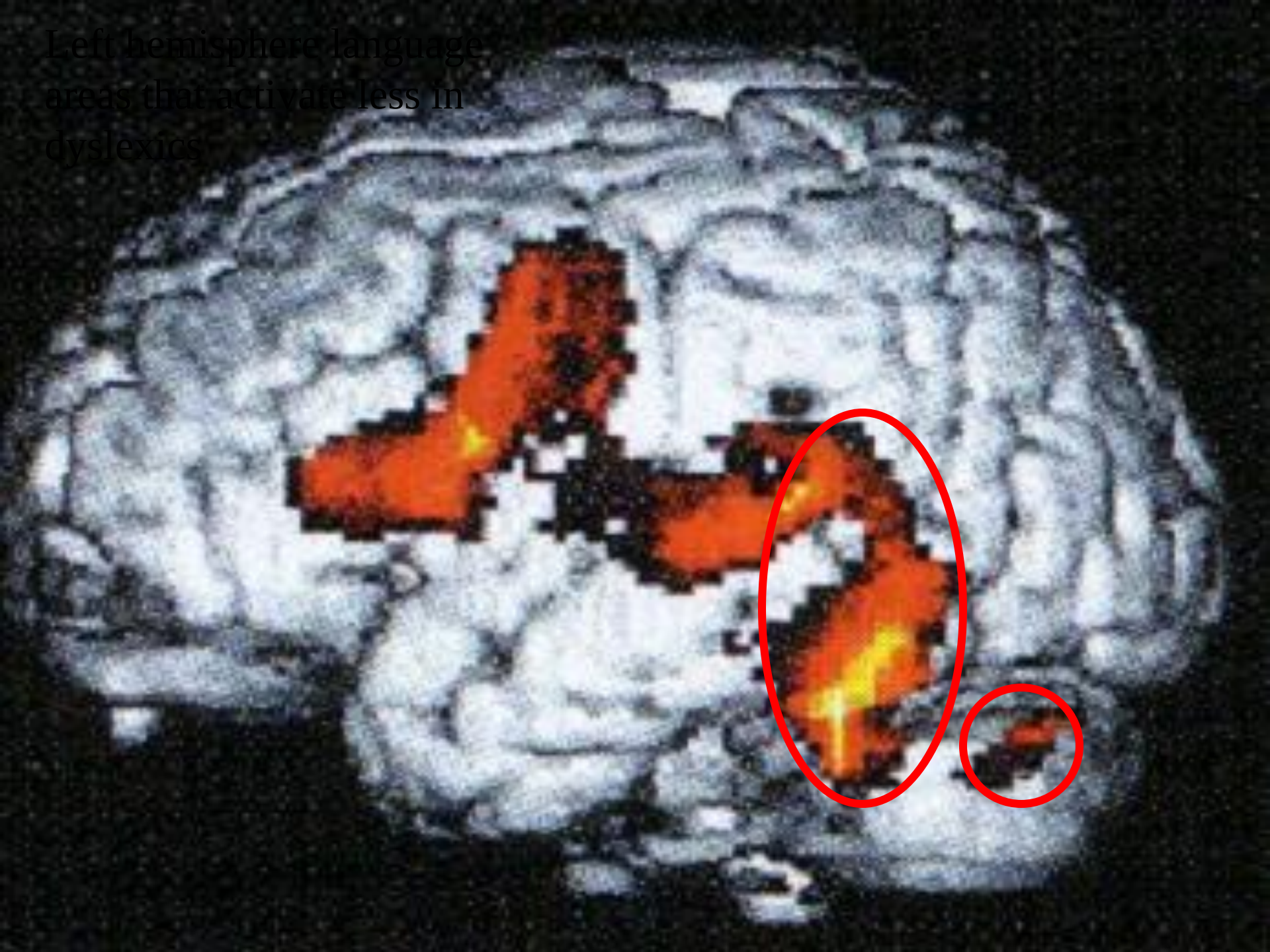


2nd trimester ectopias in dyslexic brain specifically affect dorsal visuomotor stream

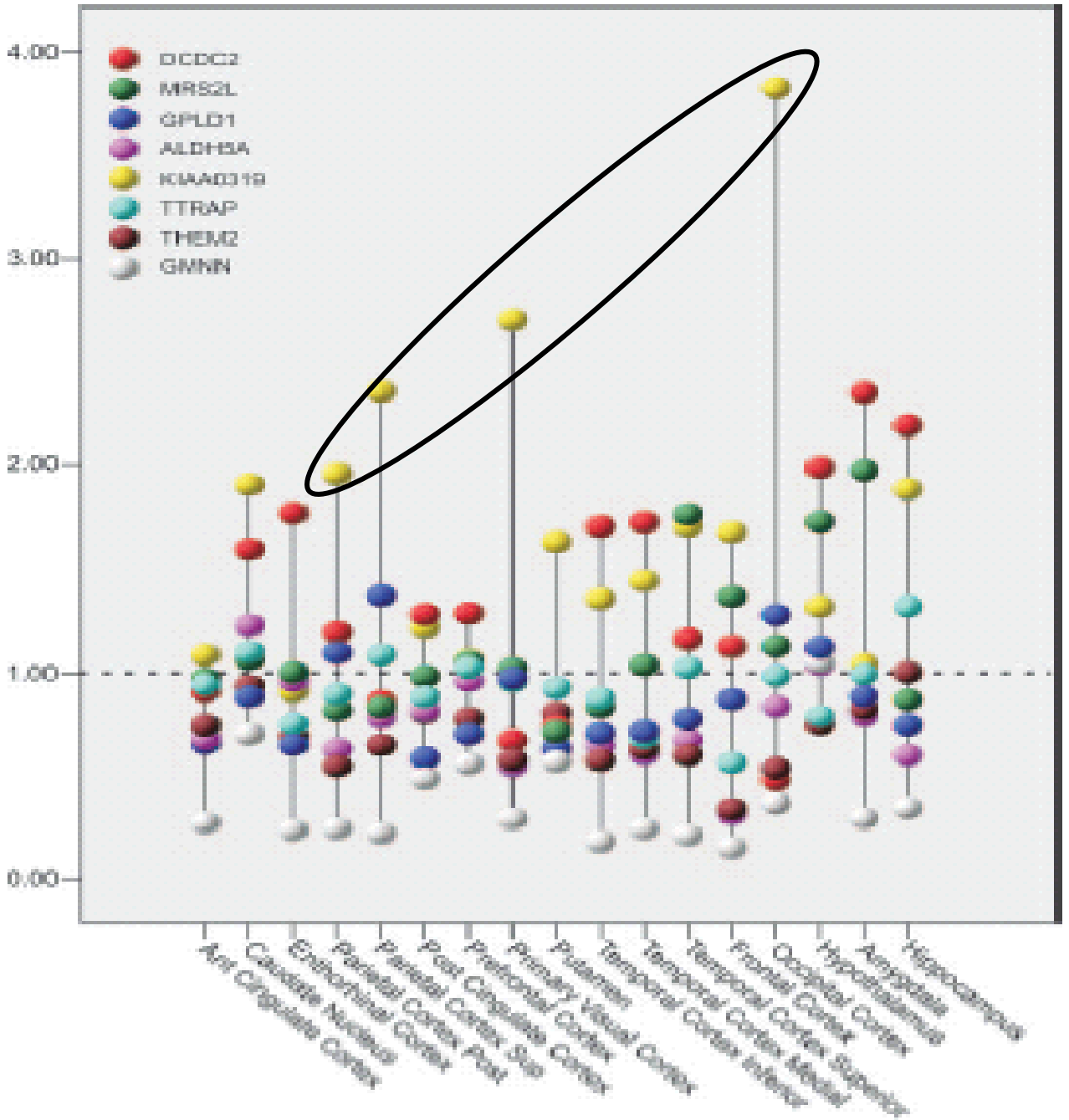







Left hemisphere language areas that activate less in dyslexics

KIAA 0319 is strongly expressed in visual magno-cellular pathway



C6p KIAA mutation?

- KIAA underexpression disrupts neuronal migration early in brain development
- Controls expression of cell surface recognition molecules
- Fail to respond to developmental signals, enable successful contact with other magnocells
- Could explain why the development of magnocellular neurones is impaired in dyslexia

What causes phonological problems?

- Impaired visual magnocellular function
- Impaired auditory magnocells
- Due to **genetic** vulnerability
- This knowledge is exciting because these weaknesses can be remedied