Cerebellum and Cognitive-Sensori-Motor Skill in Developmental Dyslexia

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Plan of Talk

1. Dyslexia and Reading
   - What Changes?
   - What needs to change!?
2. Dyslexia and Learning
   - Dyslexia and Automaticity
   - Dyslexia and the Cerebellum
   - Dyslexia and Neural Systems
3. Treatment of Dyslexia
   - Maturation
   - Inoculation
   - Adaptation
   - Acceleration
   - Inspiration
4. Conclusions

Definition: Developmental Dyslexia

“a disorder in children who, despite conventional classroom experience, fail to attain the language skills of reading, writing and spelling commensurate with their intellectual abilities”.

World Federation of Neurology (1968)

Specific Learning Difficulties
Learning Disability
Reading Disability

Reasons for high interest in dyslexia

1. high incidence in Western populations
   (~5-10% is a typical estimate, Badian, 1984; Jorm et al, 86)
2. high financial stakes
   (statutory requirement in many Western countries to provide educational support for children with dyslexia).
3. Challenging paradox to a wide variety of researchers — why do these articulate, intelligent people show such a problem in one of our most routine skills?

→Continuing high international public profile
e.g. US NICHD (National Institute of Child Health and Human Development) dyslexia funding now ~ $15m p.a. since 1985

What and Why Weaknesses …

Deficit Theories of Dyslexia

1. Behaviour
2. Cognitive Level
3. Brain Level
4. Genetic Level

Phonological Deficit

Double Deficit

Rhythm Deficit

Visual Attention Deficit

Cross-Modality Deficit

Automaticity Deficit

Procedural Learning Deficit

Temporal Deficit

Magnocellular Deficit

L Hemisphere Language

Testosterone Hypothesis

Cerebellar Deficit

24 candidate genes…

Mature Reading Circuits

Yeatman et al. (2012) PNAS

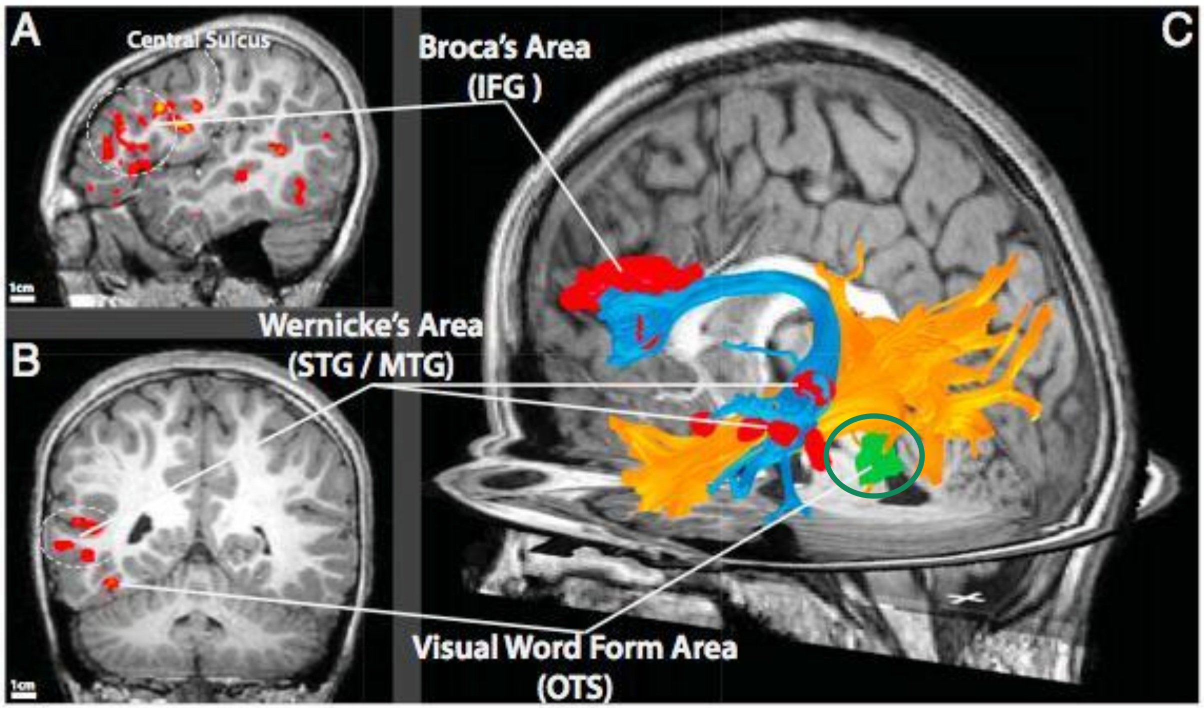


Fig. 1. Essential cortical circuits and white-matter connections for reading. (*A* and *B*) Blood oxygen level-dependent responses in a 10-y-old engaged in a rhyming task. In alternating 12-s blocks the subject judged if a pair of written words rhyme or whether two line patterns are the same. The subject's gray matter was segmented, and regions within the cortex with reliable task-related modulations ($P < 0.001$, uncorrected) were identified (colored overlay). A sagittal and coronal plane are shown to illustrate the phonological processing-related activations in the inferior frontal gyrus (IFG; Broca's area) and superior/middle temporal gyrus (STG/MTG; Wernicke's area) and the orthographic processing-related activation in the occipito-temporal sulcus (OTS). (*C*) Responsive voxels from Broca's area and Wernicke's area were rendered in 3D and displayed as surfaces within the brain volume (red). Two large fascicles, estimated with deterministic fiber tractography, are shown also. The arcuate fasciculus (blue) may carry phonological signals from the posterior temporal lobe to the inferior frontal lobe. The VWFA activation is rendered as a green surface. The ILF (orange) may carry signals from the VWFA to the anterior and medial temporal lobe.

What needs to happen for fluent reading

1. Automatise sub-skills
    - Letters
    - Grapheme-to-phoneme
    - Orthography
    - Word fixation
    - Speech internalisation
2. Co-ordinate sub-skills
    - Predictive eye movements
    - Eye-voice span
    - Lexical look-up
3. Build and rebuild the necessary neural circuits
    - Phonological circuit
    - Visual Word Form Area
    - Circuit building
    - Circuit coordination
    - Circuit myelination

Cognitive-Sensori-Motor Interactions

Senses

- Eyes — Eye movements, eye focusing, binocular vision, vestibulo-ocular reflex
- Taste — Tongue movements, biting, texture
- Touch — Active exploration
- Smell — In most animals active sniffing etc.
- Ears — In most animals ears move
- Proprioception — mostly active, continual updating
- Mirror neurons — vision to imitation

Cognition

- Language-based
- Internalised speech…

Nicolson and Fawcett Theory
Dyslexia and Learning
Phase 1: 1988-1995

Dyslexia as a Learning Disability: The Automatisation Deficit Hypothesis

The ‘correct’ description of dyslexia is ‘Specific Learning Difficulties’ or ‘{Specific} Learning Disability’

Dyslexia is [some] general deficit in learning

- For some reason it is difficult for dyslexic children to become ‘expert’ in a task
- ………………...whether it is a cognitive task or a motor task.

The Automatisation Deficit hypothesis (N & F 1990)

- Dyslexic children have problems making skills <u>automatic</u> and need therefore to ‘consciously compensate’ even for simple skills

Nicolson & Fawcett Theory
Phase 1 (1988-1995)

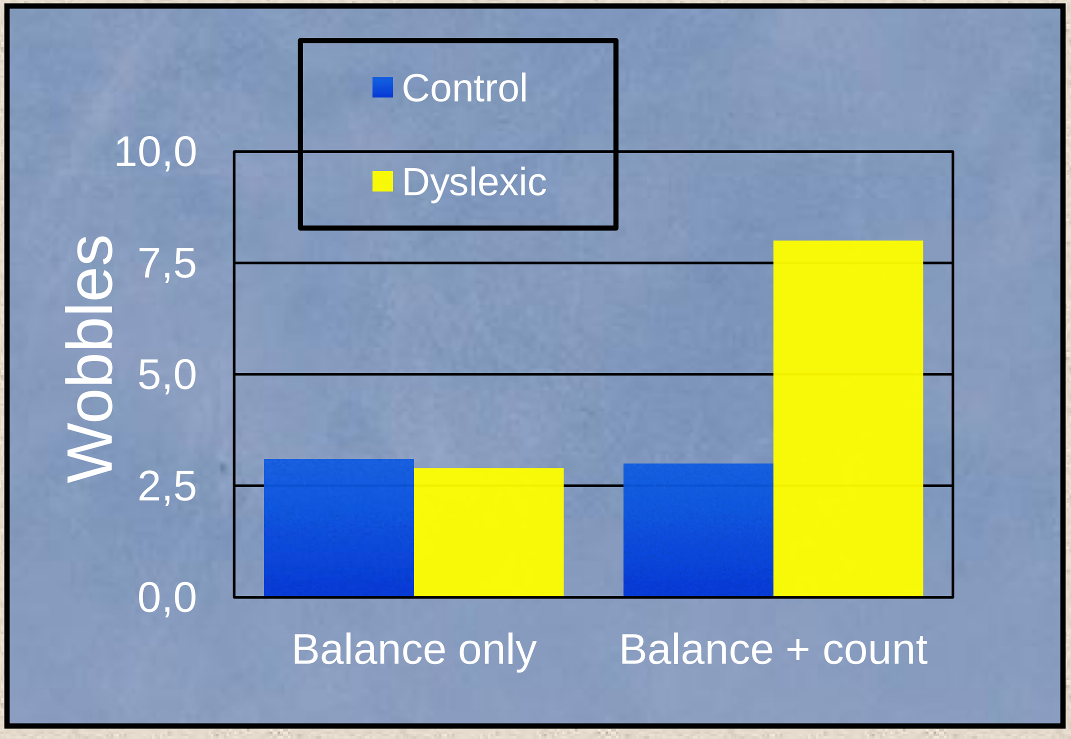
Logic

- Reading-related tests do not discriminate between the theories
- What is needed is a test in a domain where the theories predict no deficit - this is Popper’s falsification approach.

We tested their motor skills. They were worse than normal - even for the highly practised skill of balance!

Study 1: Balance and Dyslexia

Nicolson & Fawcett: Cognition (1990)



Under optimal conditions dyslexic children can balance as well as controls.

The controls balanced automatically.

The dyslexic children did not.

There seem to be automatisation problems even for balance!

Study 2: Procedural learning (1992/2000) Blending of primitive skills (N&F, EJCP 2000)

(i) Problems with initial blending

(ii) more errors

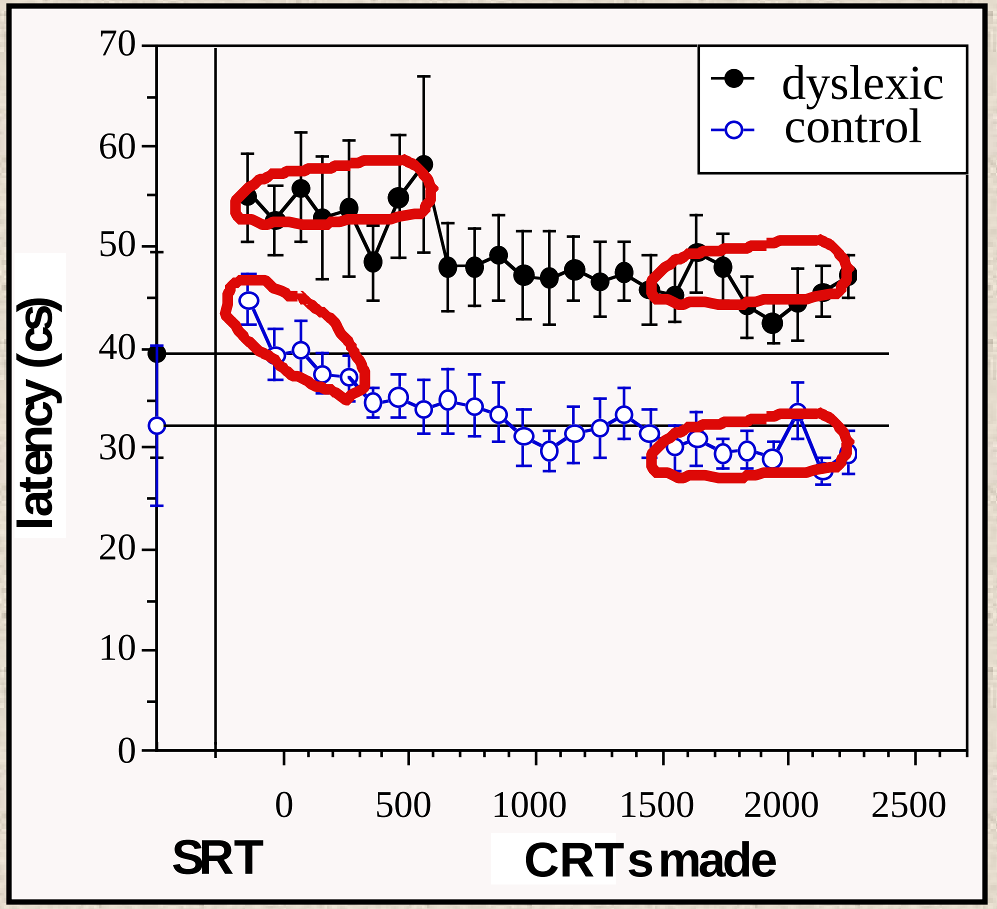
(iii) Slower final performance

(iv) slower learning

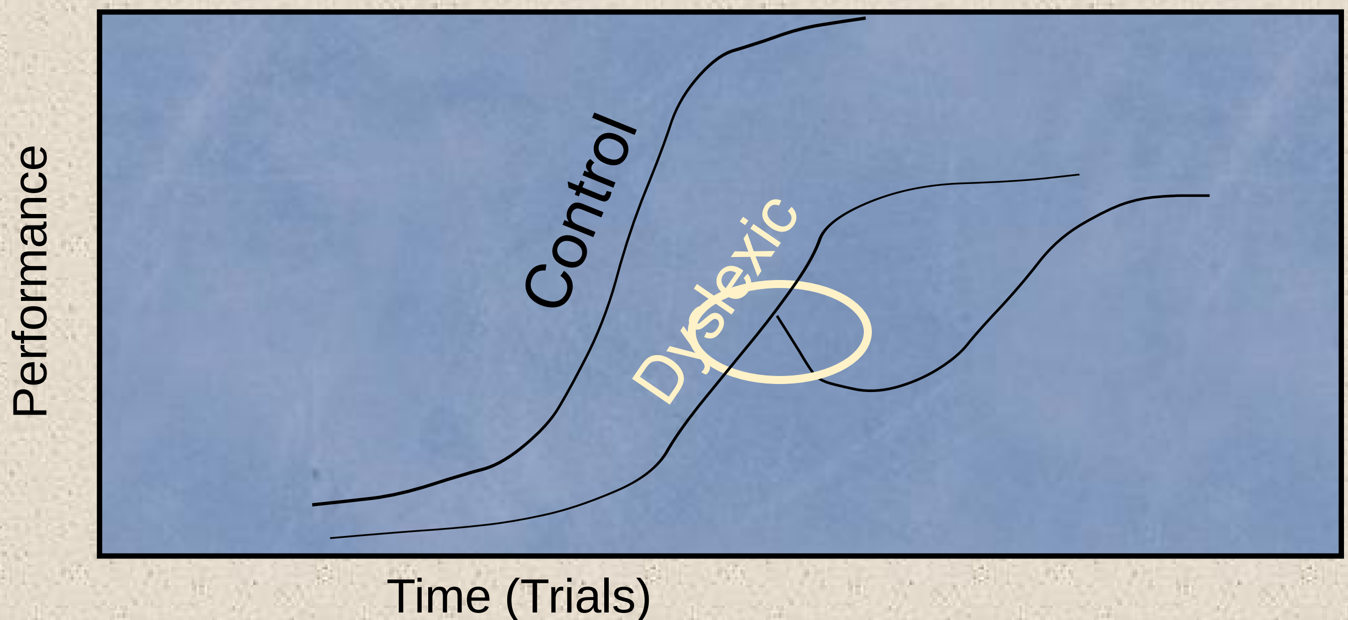
$t = 53.9\ n^{-0.07}$ (dys)

$t = 39.4\ n^{-0.14}$ (cont)

[t is time taken, n is number of trials practice]



The difficulties lie at the Start, the Middle, the End and the Blend

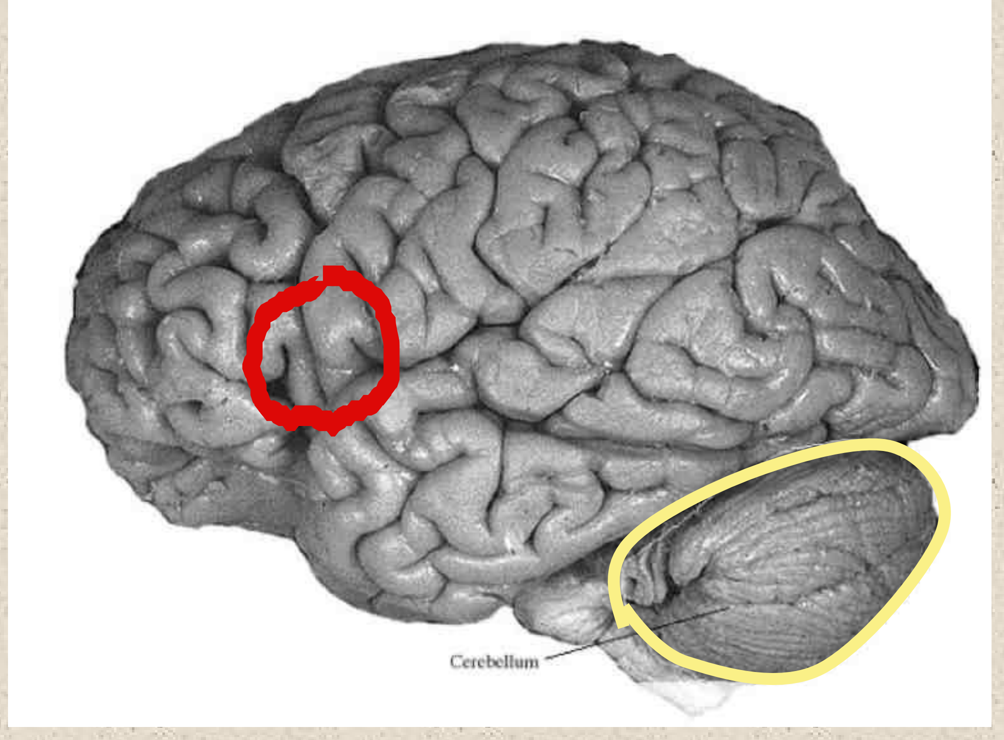


The 'square root' rule:

- The extra time needed for a dyslexic child to master a task is proportional to the square root of the time a non-dyslexic child takes.
  - *So if it takes 16 trials normally, for dyslexia would take 64*
  - *If it takes 100 trials normally, for dyslexia would take 1,000*
- Extremely disconcerting if generally true - the 1000 hour rule - but explains difficulties in remediating reading.

Nicolson and Fawcett Theory
Phase 2-3 (1995-2001, 2001-7)
Learning – Cognitive Neuroscience

Theory – The Cerebellum



In humans, 10-15% of brain weight, 40% of brain surface area, 50% of the brain's neurons.

The 'hind brain'. Dexterity, automaticity.

"… the 2-way connections linking the cerebellum to Broca's area make it possible for it to improve language dexterity, which combines motor and mental skills."

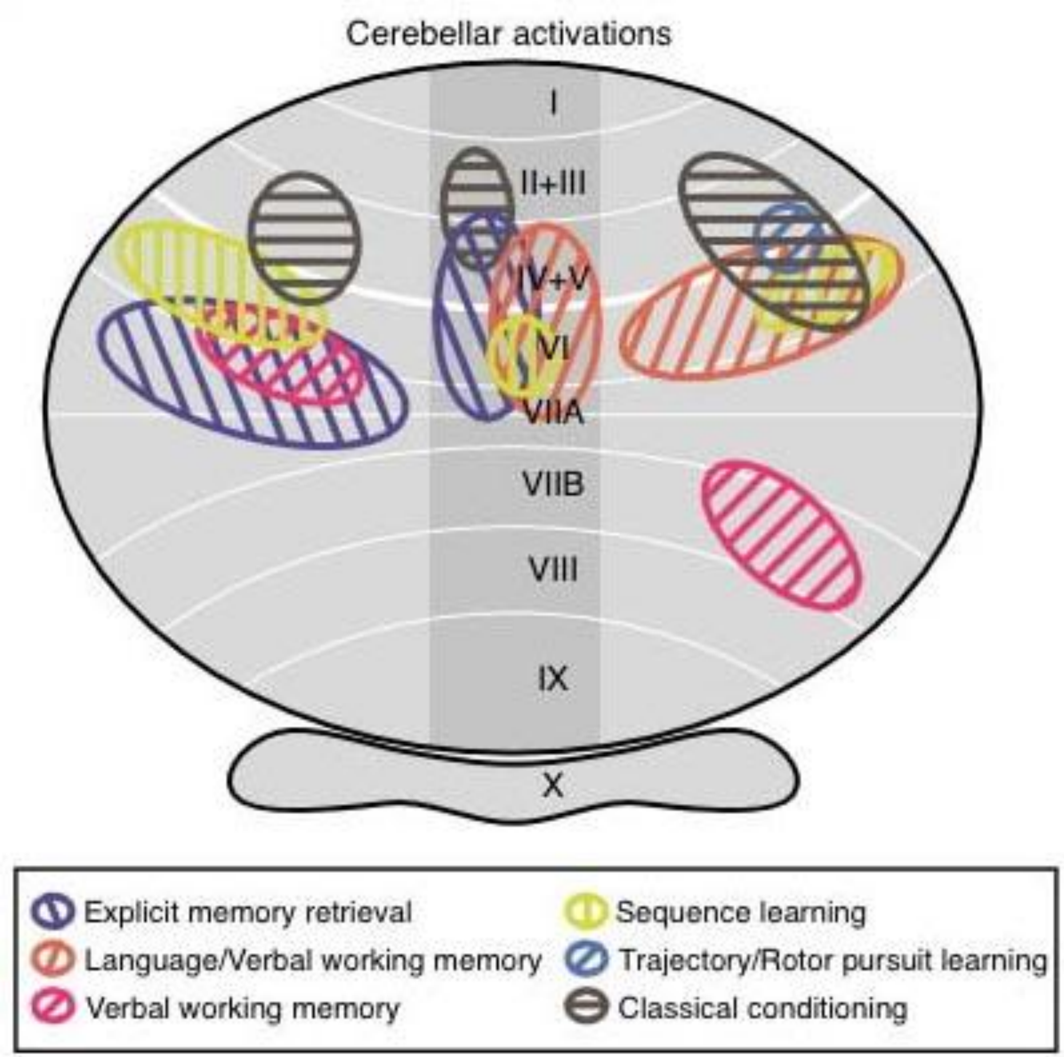


Fig. 1 Schematic diagram of the unfolded cerebellum illustrating the locations of activations described in this review. Roman numerals appearing in the cerebellar vermis (illustrated by the darker shaded region along the midline) denote the lobule identification based on Larsell's[80,81] nomenclature. For the human cerebellar vermis, they correspond to the following lobules: lingula (I), Centralis (II+III), Culmen (IV+V), Declive (VI), Folium vermis (VIIA), Tuber vermis (VIIB), Pyramis (VIII), Uvula (IX), Nodulus (X). Corresponding lobules in

Cerebellar Activation in Cognitive tasks

(Desmond & Fiez, 1998)

NB.

Working memory

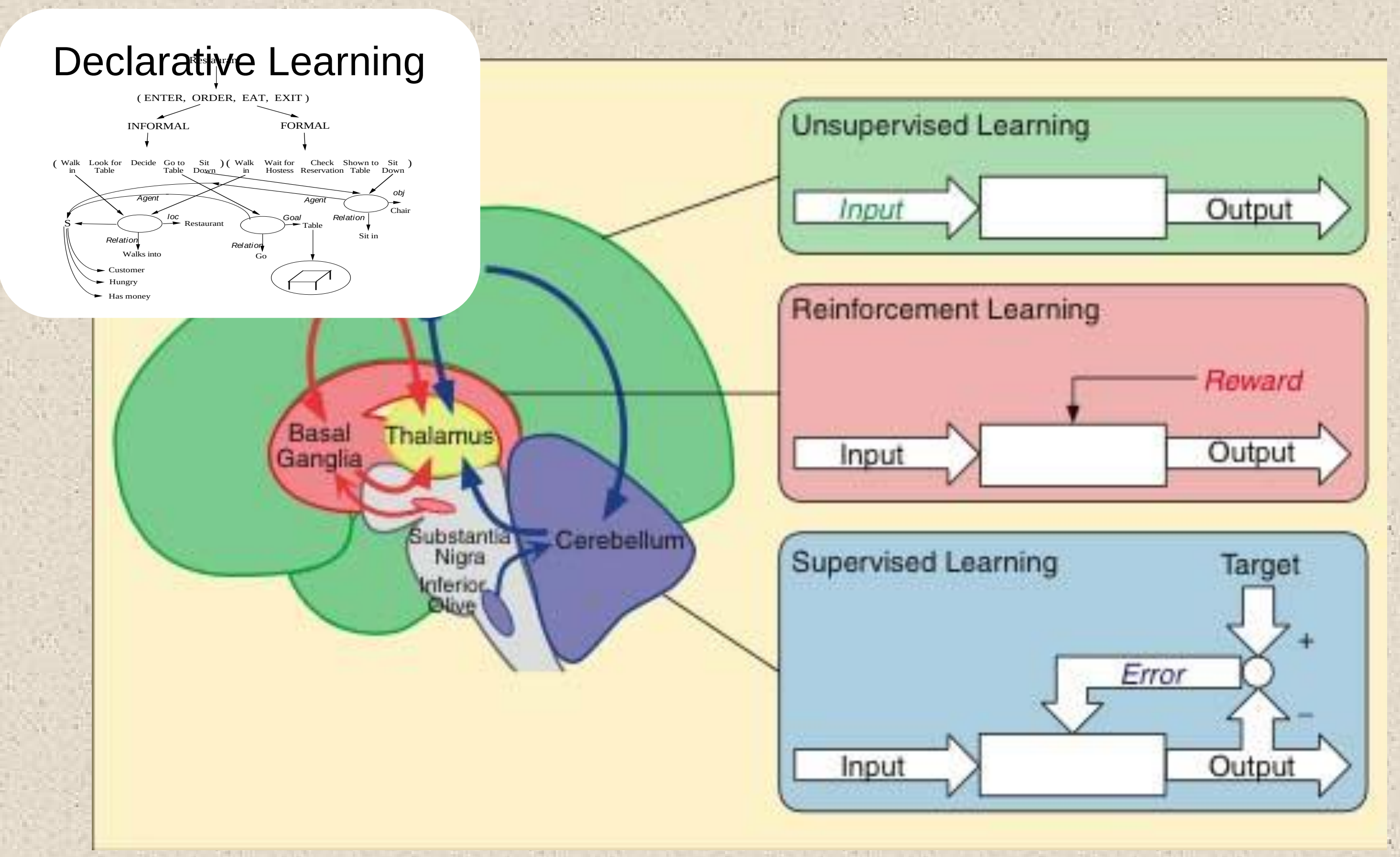
Language

Also reading

Both declarative and procedural knowledge

Learning Mechanisms and the Brain: Doya (99)

Declarative Learning



1. Frequent Input
2. Occasional success
3. Imitation
4. Tuning

All regions of the brain support unsupervised (statistical) learning

Only the basal ganglia support Reinforcement learning (ie success-based)

Only cerebellum supports supervised learning (target + error signal)

Hence brain regions need to work together through networks

Declarative vs Procedural Memory / Language systems

1. Declarative Memory System

- The mental lexicon
- temporal-lobe substrates of declarative memory, hippocampus
- storage and use of knowledge of facts and events.
- ‘ventral route’

2. Procedural Memory System

- The mental grammar
- rule-governed combination of lexical items into complex representations, depends on a distinct neural system.
- network of specific frontal, basal-ganglia, parietal and cerebellar structures
- underlies procedural memory, which supports the learning and execution of motor and cognitive skills, especially those involving sequences.
- ‘dorsal route’

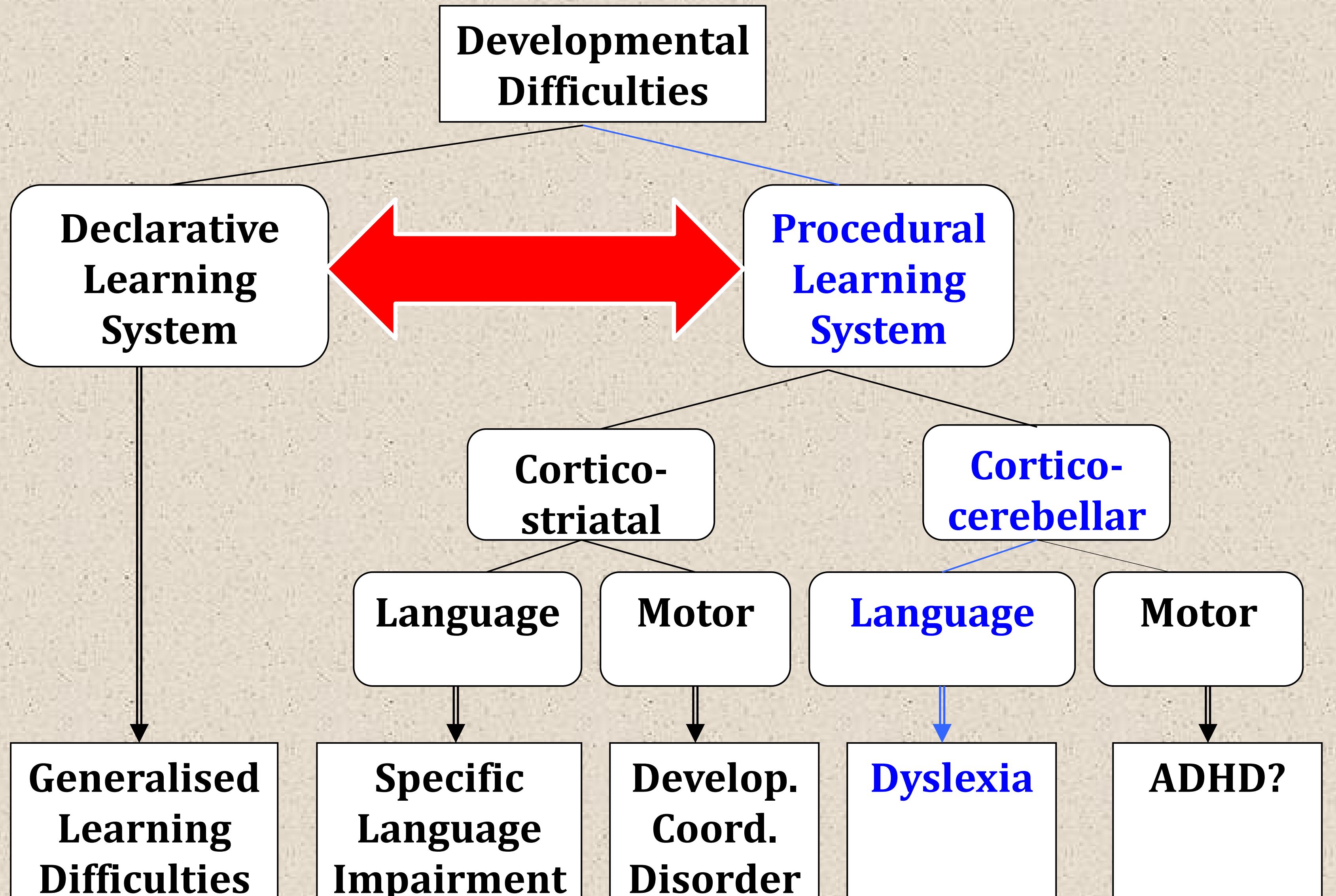
Procedural Learning Deficit (PLD) Hypothesis

1. Many developmental disorders are attributable to abnormal function of the PM system
   - I prefer to call it the Procedural Learning system, to highlight its role in plasticity as well as memory.
   - There are two different PL systems, the motor PL system and the language PL system

2. For dyslexia, we have Specific Procedural Learning Difficulty - specific to the language-cerebellum, but involving other PL components to a greater or lesser degree.

Declarative vs Procedural Circuits

Nicolson & Fawcett, TINS, 2007

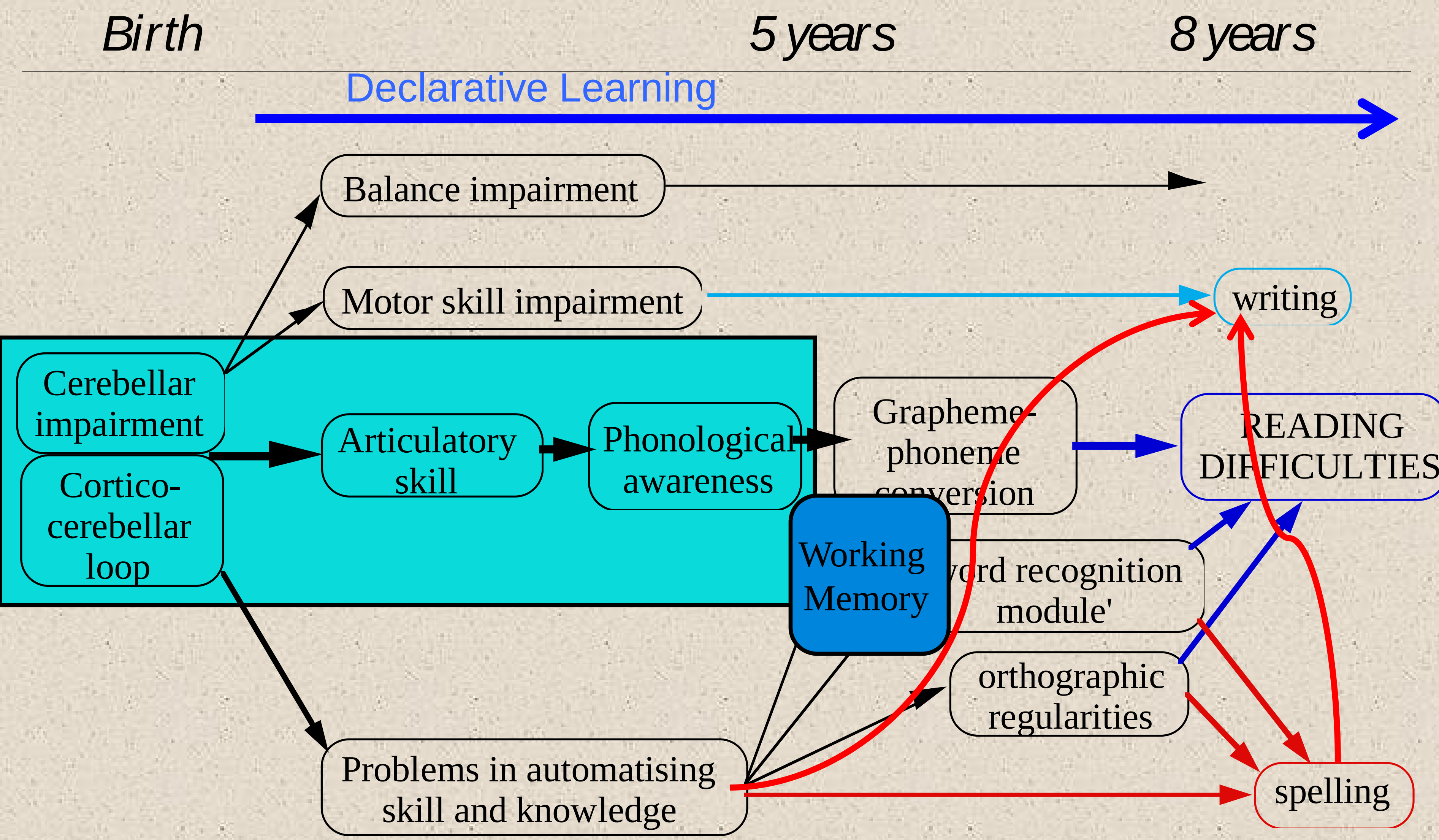


Recent Evidence for the Framework

1. Children with dyslexia have better learning and retention in declarative memory than typically developing children (as tested through a recognition memory paradigm, with dyslexics having recognition advantages both a few minutes and one day after encoding (Hedenius & Ullman, 2013).
2. Meta-analysis of serial reaction time studies (implicit learning) shows consistent effect, coupled with consistent problems in procedural learning (Lum, Ullman and Conti Ramsden, 2013)
3. Deficit in consolidation of procedural skill automatization in dyslexia in children. Also greater impact on procedural learning of letters than motor sequences (Gabay, Shiff and Vakil, 2012)

Dyslexia: an ontogenetic Causal Chain

(Nicolson, Fawcett and Dean, 2001/7)



Dyslexia:
Implications for Support

Jump

How to help children learn?

1) Maturation
   - Patience! Don’t force immature systems
2) Inoculation
   - Create an environment in which children can develop the pre-requisite skills for reading, naturally, before school
3) Adaptation
   - If a dyslexic child cannot learn the way we teach, we must teach him (or her) the way he (or she) learns
4) Acceleration
   - Try to improve the ability to learn. Cognitive, Belief, Brain
5) Inspiration
   - See successful outcomes, follow your star!

Maturation

We have suggested (Nicolson and Fawcett, 2014) that dyslexic children show 'Delayed Neural Commitment'

- Automatisation takes longer and requires higher quality experience
- If sub-skills are not fully automatised, they cannot form the foundation for building further skills (bad)
- If a sub-skill is over-automatised (without linking to other key skills) it can never be integrated with them
- Forcing automatisation of one subskill (phonics) before the other subskills have matured (executive function, inner speech, eye control, attention) can be disastrous

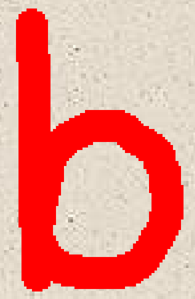
It is much safer to allow maturation to take place naturally rather than try to force it

Inoculation

- Term from Seligman – build up resilience
- Create an environment in which dyslexic children (or those at risk of dyslexia) are able to develop the skills and attributes needed to overcome the difficulties they will have when starting to learn to read
- Relate to personal experience
- Learn by ‘osmosis’
- Use mnemonics to help learn letters before school
- Manual control practice

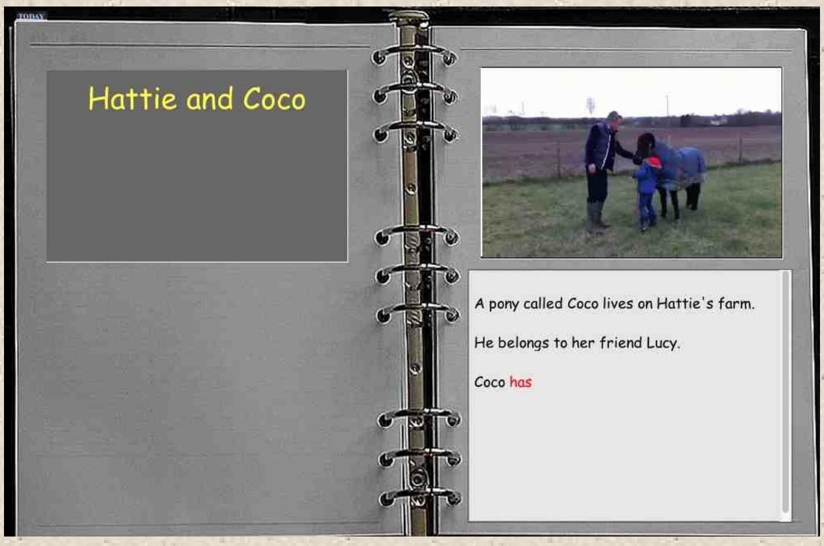
My Letter Actions App

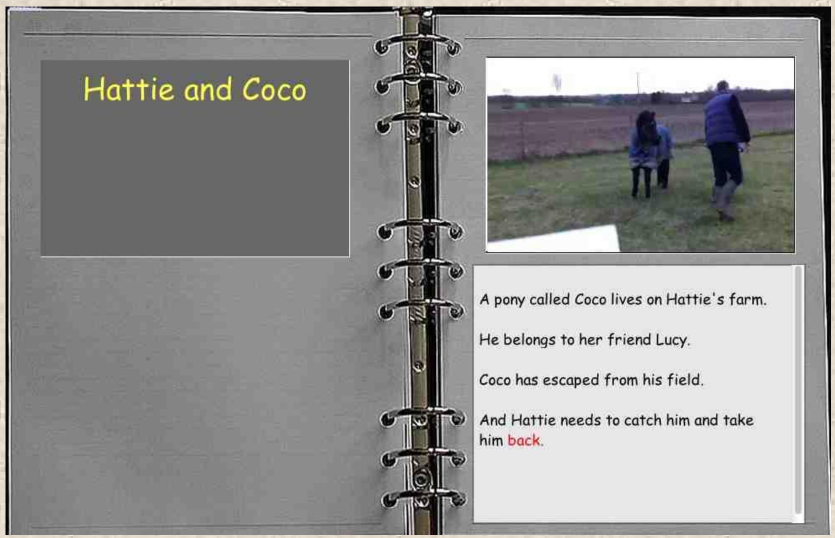
1. b is for buzzy bee. He buzzes towards the flower, stops and drinks some nectar, then buzzes around in a circle looking for some more.
    - Like this…
    - Can you help buzzy by tracing along the path…



- d is for danny dog. He likes to play fetch. Can you see here he's next to you, he goes round in a circle, you throw the ball and he dashes after it, brings it back, and drops it for you.
    - Like this…
    - Can you help danny by tracing along the path…

Read-with-Grandma app!





Adaptation

- If a dyslexic child cannot learn the way we teach, we must teach him (or her) the way he (or she) learns
- Optimise the learning conditions
- Mnemonics
- Declarative Learning
- Use new technology
- Touch-typing
- To complement the teaching that is done at school

Acceleration

- Try to improve the ability to learn
- Teach strategies
- Make more assertive – avoid confusion
- Consider brain-based learning
    - nutrition
    - ‘brain games’
    - Coloured lenses
    - Cerebellar stimulation
- The optimal intervention will be specific to the individual and requires analysis of learning abilities as well as disabilities

Inspiration

- Find the child’s strengths and try to work towards them!
- Inspirational stories of high achieving dyslexic adults
- Immediate accessibility (internet)
- Opportunities to develop individual strengths

Follow your star!

Why Now?

1. First wave (disability awareness) completed
   - Awareness
   - Legislation
   - Representative bodies
2. The Science is right for Individual Dyslexia
   - Positive Psychology
   - Cognitive Neuroscience of learning
   - Genetics and epigenetics of learning
3. Tools are there for Positive Dyslexia
   - Social Media
   - Apps
   - The knowledge economy

Conclusions: theory

Conclusions

1. Learning falls into two forms, a primitive procedural learning system scaffolded by the cerebellum and included cognitive-sensori-motor information, together with a declarative system which uses symbolic information
2. In addition to the learning processes, the brain needs to build learning circuits to support efficient transfer of information around the brain
3. There is strong evidence that dyslexic children have difficulties with procedural learning, with sensori-motro-cognitive integration, and with declarative / procedural integration.
4. It is also likely that they have difficulties with neural circuit building, and with integrating and coordinating information from different modalities and different circuits
5. The transformation in knowledge of cognitive neuroscience, taken together with the transformation in individual apps and social media, provides - for the first time – the opportunity to develop immersive learning environments that overcome these difficulties

Key References

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End of Talk