The cerebellum and its contributions to the developing linguistic cerebrum
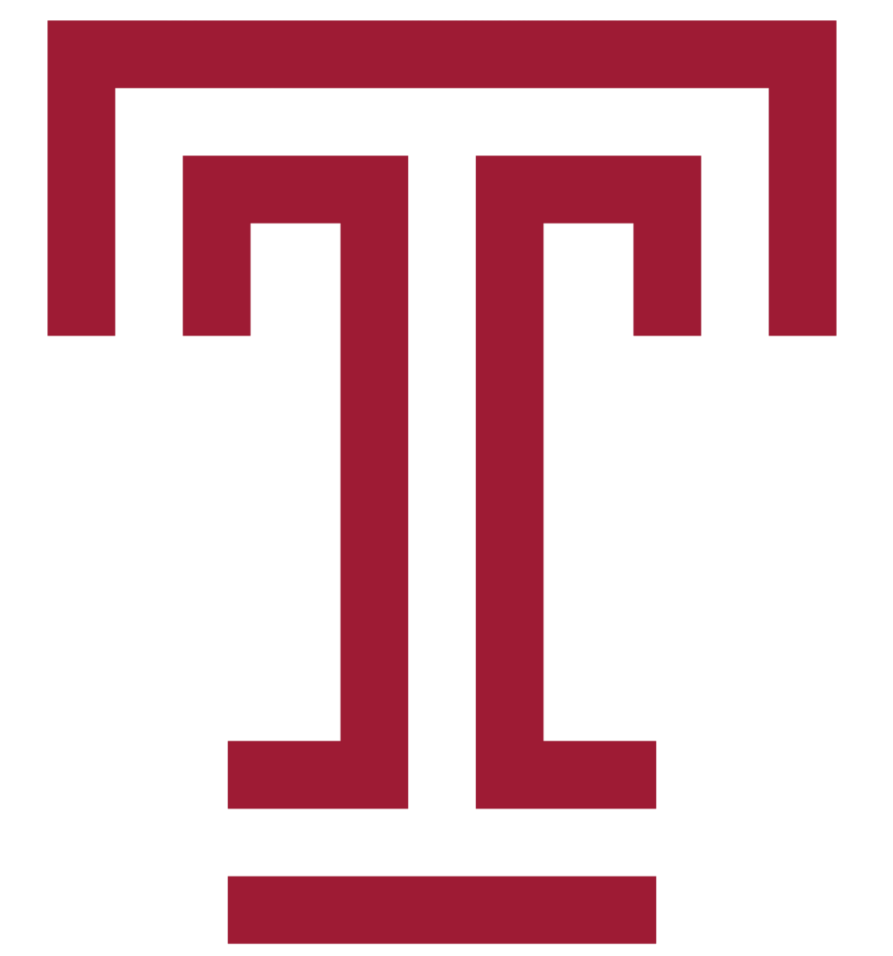
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Background

- The cerebellum has been implicated in both motor and non-motor function.
- There is evidence of some involvement of the cerebellum in linguistic functions[1].
- Damage to the cerebellum in adults has been shown to result in issues such as agrammatisim[2], anomia[3], and issues with verbal fluency[4].
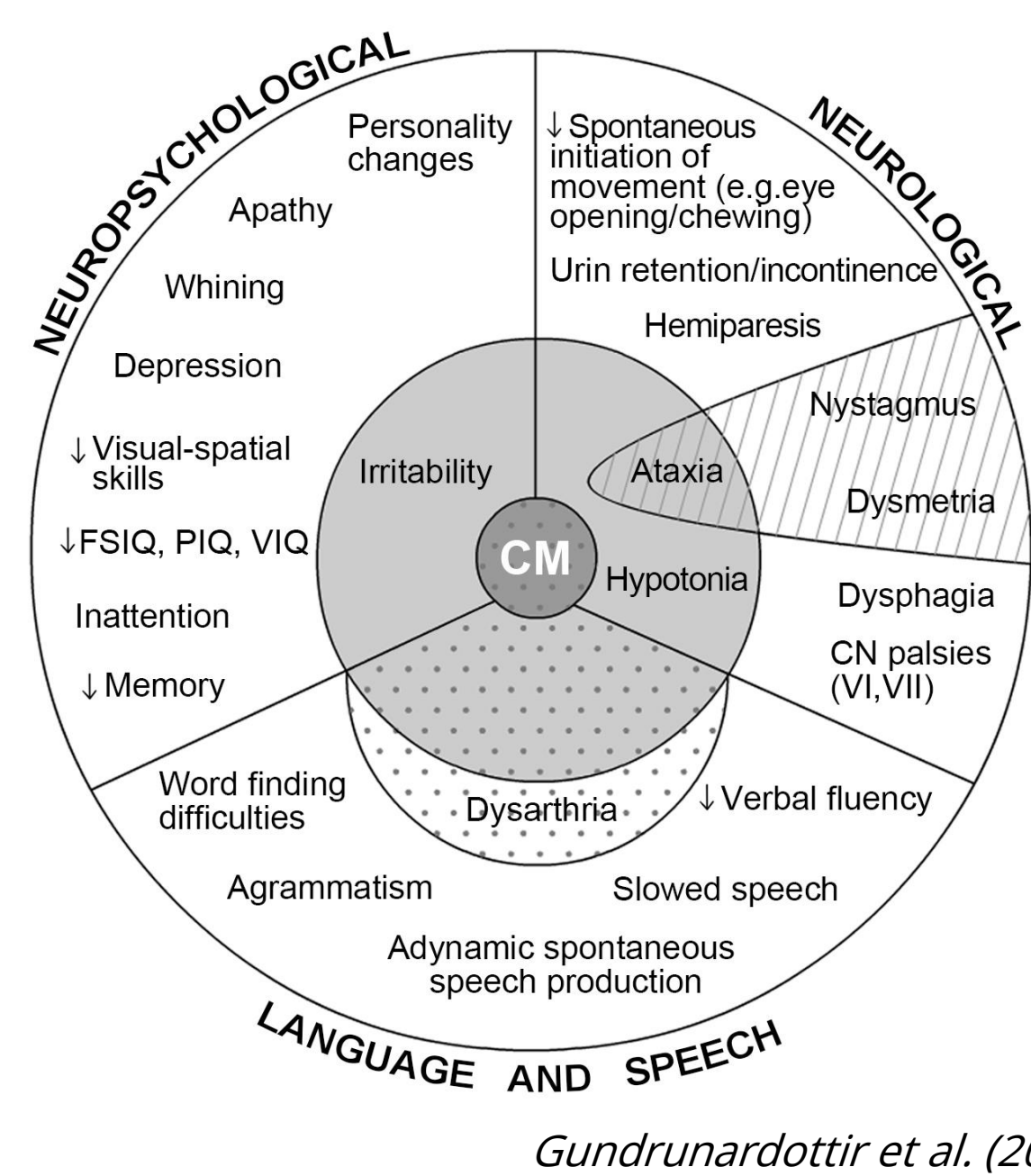

Gundrunardottir et al. (2011)

- However, many of the subsequent issues described do not persist after the acute phase (~6 months) after stroke/damage to the cerebellum.
- On the contrary, children are left with life-long deficits (linguistic and otherwise) when their cerebellums are damaged[3].
- **The cerebellum has been implicated in many developmental disorders, such as dyslexia, autism spectrum disorder, and ADHD[5].**

Motivating Question

- Children's brains are known to be generally more plastic than adults' throughout development[6].
- *This is not true for the cerebellum*

What role does the cerebellum play in language development?
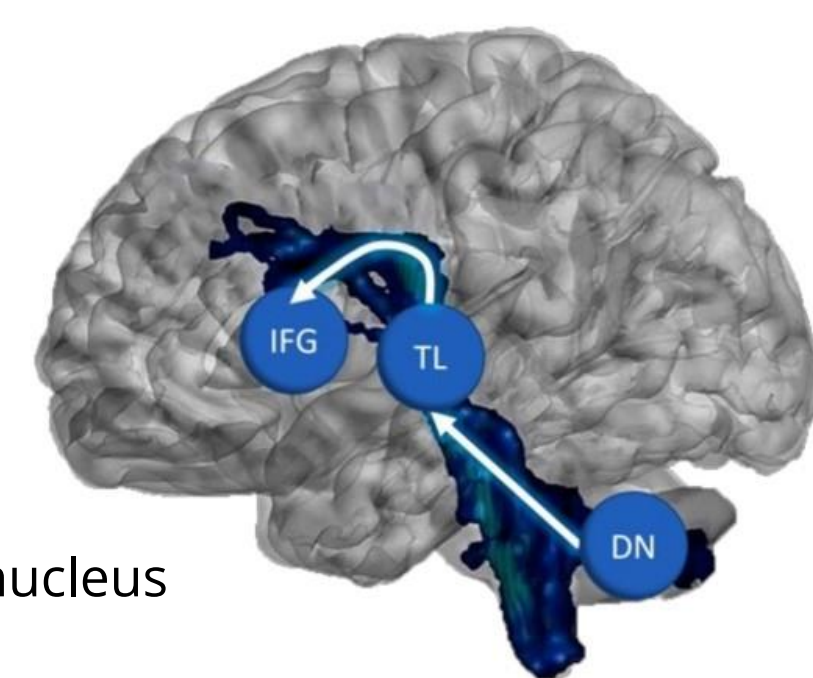
DN = dentate nucleus
TL = thalamus
IFG = inferior frontal gyrus

Jobson et al. (2022)

Current Literature

Early Life CB Damage

- Posterior fossa tumor[7]
- Premature birth[8]
- Genetic disorders[9] (Joubert's syndrome, William's syndrome)
- Perinatal stroke[10]

CB Outcomes:

- Language delays[11]
- Mutism[12]
- Syntax and grammar deficits; receptive and expressive[13]
- Phonological awareness[14]
- Naming[11]

Development of cerebellar anatomy:

- The third trimester of gestation shows the largest period of growth for the cerebellum[15]; hence why something such as premature birth would affect the development of this structure.
- The cerebellum is one of the first structures that is fully-formed[16].
- It is tightly packed with neurons, holding 3x the number of neurons than the cerebrum[17].
- The primary input and output pathways are the cerebellar-thalamic-cortico (CTC) and cortico-ponto-cerebellar (CPC) pathways.
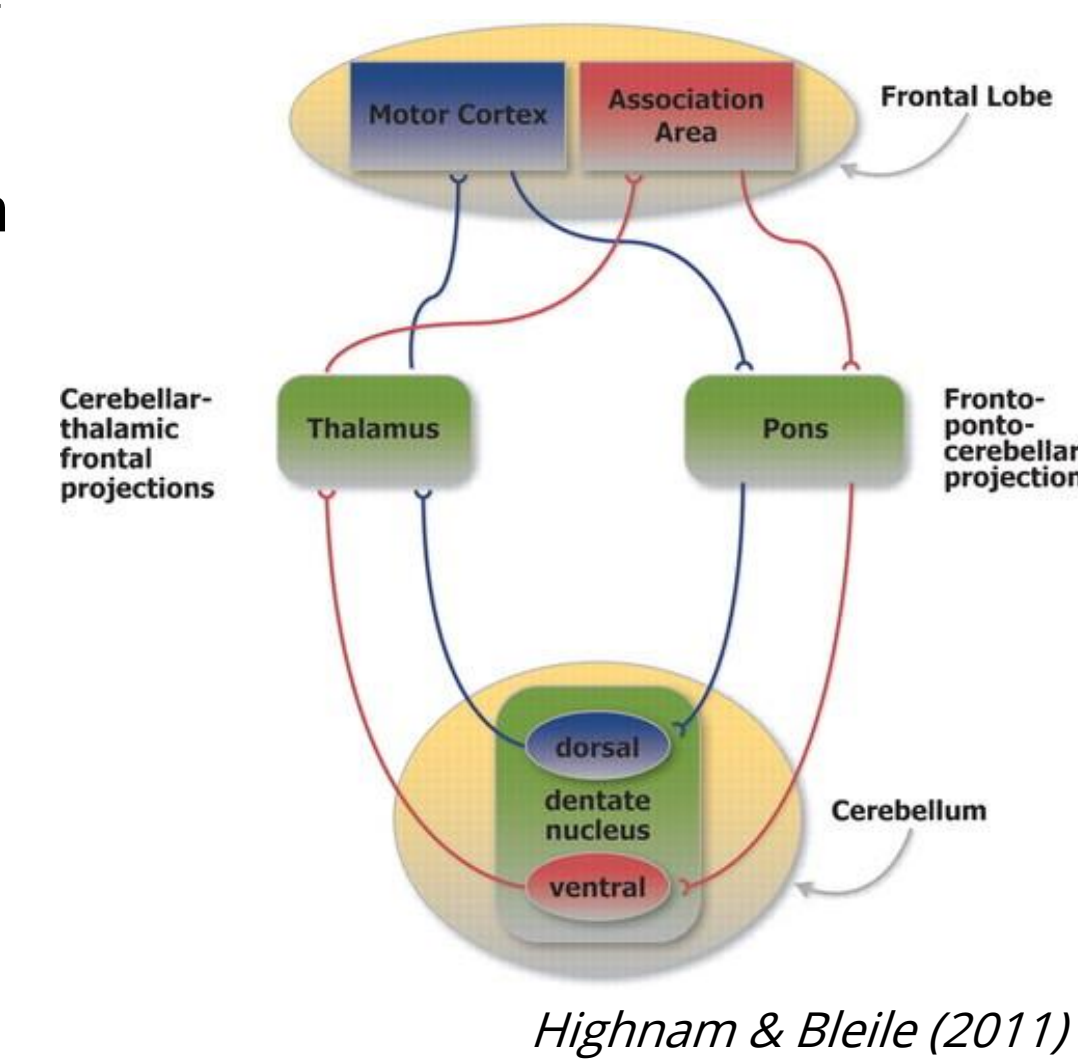
Highnam & Bleile (2011)

Popular Theories

The most popular computation theories of the cerebellum all rely on the idea of an *internal model*; this is our internal representation of the world and how it works based on our previous experience[18].

Prediction

The cerebellum may use internal models to make moment-to-moment predictions and adjust behavior using those predictions[19] – e.g. predicting the ending of a sentence[20].

Timing

The cerebellum may use internal models for temporal relationships between sensorimotor events[21]. This can be seen in prosody, where timing is essential to successful execution.

Sequencing

The cerebellum uses internal models to produce and comprehend sequential events[22] whether that is in relation to social[23], or motor[24] information.

Sample Case Studies

| CITATION	PATIENT INFO (AGE OF INSULT)	CAUSE OF CB DAMAGE	LANGUAGE OBSERVATIONS
Hudson, Murdoch & Ozanne (1989) *(Case 2)*	Male, 2 years old 7 months	Midline posterior fossa tumor	Patient exhibited global language deficits that included all aspects of expression and reception
Tavano, Fabbro & Borgatti (2007) *(Case 1)*	Male, 9 years old	Enlargement of the fourth ventricle	Morphosyntactic and phonological abilities were impaired; grammatical comprehension was impaired (difficulty with all structured sentences)
Riva & Giorgi (2000) *(n = 7)*	Mean age 9.8, range of 6.11–13.4 years	Right cerebellar astrocytoma for all cases	Naming, comprehension, and receptive syntax were found to be impaired
Aarsen et al., (2004) *(Cases 6, 8, 11)*	Ages: 16 years and 4 months old; 16 years and 8 months old; 8 years and 6 months old	Dorsal vermis astrocytoma; tumor covered both hemispheres & vermis; medial right hemisphere astrocytoma	Patients exhibited semantic-pragmatic deficits
Lewis & Murdoch (2010) *(Case 3)*	Female, 10 years 3 months	Midline medulloblastoma with damage to third and fourth ventricles	Receptive language score was ≥ 2 standard deviations below control cohort
Di Rocco et al. (2011) *(n = 11)*	Average age 6.73 years, range of 2-11 (6 female, 5 male)	Posterior fossa tumors in various locations (vermis, IV ventricles, right cerebellar hemisphere, left peduncle)	Lexical retrieval, lexical comprehension
Docking, Murdoch & Ward (2004) *(n = 9)*	Average age of 6 years, range of 2-11 (6 male, 2 female, one child unreported)	Posterior fossa tumor	Phonological awareness (5/9), general linguistic deficit (3/9), high-level language deficit (6/9)

Case Study Take-Aways

A thorough investigation of the literature reveals that damage in early life produces relatively worse effects on language than later in life. However, the affected linguistic domain varies across studies.

## Explanations for Cerebellar Involvement in Development

The most popular theory about the cerebellum's role in development is that it **trains the cerebrum** – but what is the cerebellum training the cerebrum in?
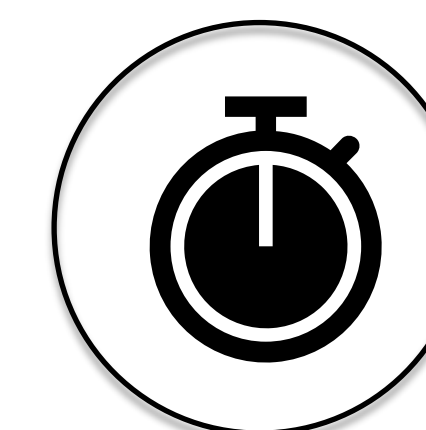
Timing in essential for prosody and the back-and-forth of conversation[32,33], both of which the cerebellum is involved in. **Timing**
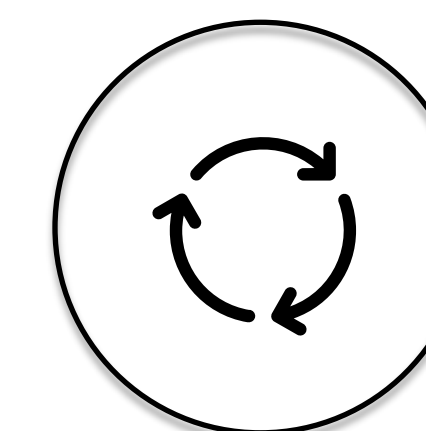
Fluent speech requires rapid evaluation of sensorimotor input[34], which the cerebellum is involved in. This could be related to both *prediction* and *timing*. **Fluency**
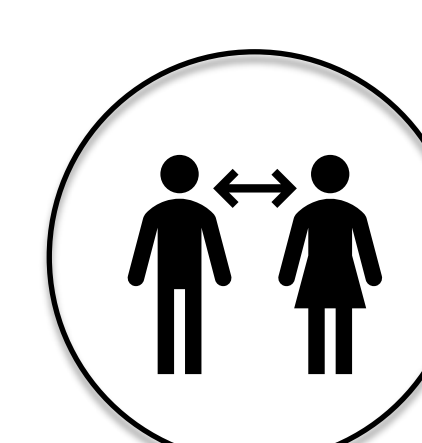
Social interaction is a core influence on language development[35]; the cerebellum has been shown to be heavily involved in social interaction[23]. The primary theory is that *sequencing* is most involved in social interaction. **Social**

Remaining Questions

1. Does the cerebellum perform the same computation on all language domains (i.e. syntax, phonology, etc), or does it play a different role in different language domains?
2. Developmental disorders (e.g. dyslexia and autism) have been linked to cerebellar dysfunction[5]. What is the role of the cerebellum in developmental disorders with a language component?
3. Is there a critical period during which cerebellar damage affects language comprehension more severely?
4. To what extent is there overlap between language and social functions? Social interactions influence language development[35] but the extent to which these two are intertwined regarding the cerebellum needs further investigation.

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