The human brain starts working the moment you are born and never stops until you stand up to speak in public.  
(George Jessel, actor)

1. Stuttering as a lack of cerebral dominance (Orton and Travis)
2. Stuttering as a timing disorder (Van Riper)
3. Stuttering as a right hemisphere dominance disorder (Moore)
4. Stuttering as a right hemisphere interference disorder (Webster)
5. Stuttering as a basal ganglia disorder (Alm)

We are not blind – we tend to look at the stuttering brain through a high-powered microscope rather than a wide-angle lens.
I used to think that the brain was the most wonderful organ in my body. Then I realized who was telling me this. (Emo Philips, Comedian)


**BEHAVIOURAL DATA**
- PWS generally have slower reaction times
  - Both verbal and non-verbal
  - Independent of stimuli
  - Children and adults
- Fluency enhancing influences
  - Altered auditory feedback (DAF, masking, ...)
  - Rhythmic stimulation (metronome, singing, ...)
- Fluency disrupting influences
  - Speech rate
  - Stress factors
  - Articulatory coordinations
    - Disfluent and fluent speech
  - Motor coordination
    - Bimanual coordination
  - Sensory processing
    - Central auditory processing
    - Proprioception
  - Drug effects
  - Acquired stuttering

**ARTICULATORY DISCOORDINATION**

**VIBRATION EFFECTS ON JAW MOVEMENTS**

nonstuttering adults > stuttering adults
Non-speech movements:
Differences in proprioceptive ability

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<th>Variable Error</th>
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visual feedback

non-visual feedback

6 mm target
18 mm target

Loucks & De Nil, 2004

**KEYS TO THE BRAIN**

**IMAGING**

Techniques

fMRI
MEG
PET

**SPEECH PRODUCTION**

Normal speech production

**LANGUAGE FORMULATION**

- Meta-analysis
  - Phonology (blue)
  - Semantic (red)
  - Syntax (green)

**FUNCTIONAL IMAGING OF DEVELOPMENTAL STUTTERING**

Are the brains of stuttering and nonstuttering individuals differently activated?

Vigneau et al., NeuroImage, 2006

Loucks & De Nil, 2004

Hickok & Poeppel, 2007

McCracken et al., Neurolinguage, 2006
De Nil et al., 2003
De Nil et al., 2001
Silent Reading
Oral Reading
Verb Generation

Ingham et al., 2004
De Nil et al., under review
NS
PWS
Braun et al., 1997
Auditory deactivation/inactivation
Auditory Cortex

Gender Differences

MEG: Auditory Inhibition

Meta-analysis - Neural signatures of developmental stuttering (Brown et al., 2005)
Overactivation of the vermal region of lobule III of the cerebellum
Overactivation of frontal operculum/anterior insula
Absence of activation in auditory areas bilaterally
Are differences in activation related to sensorimotor functions, language functions, or both?

Silently thinking of the target word following an auditorily presented phrase “those funny guys at the circus” (clowns):
- Stuttering subjects tended to show more bilateral activation
- No statistical differences between the groups

Differences habitual – modified speech
- Stuttering adults > nonstuttering adults
  - Auditory cortex
  - Somatosensory cortex
  - Insula
  - SMA
  - Anterior cingulate
  - Precentral gyrus

Pacing and singing
**Differences habitual – modified speech**

- **Treatment effects**

**Stuttering treatment**

- Overt reading of short sentences.
- PreTx: bilateral activations with greater RH activations in speech motor and planning locations.
- PostTx: more LH and involves the left temporal lobe
- 2 yr followup: activations reverting to the preTx pattern but with greater spread.

**IMAGING OF DEVELOPMENTAL STUTTERING**

Are brains of stuttering and nonstuttering speakers structurally different?

- **Planum Temporale**
  - Size: stuttering > controls
  - Asymmetry:
    - Left biased in both stutterers and nonstutterers
    - Bias: stutterers < nonstutterers

**Voxel based morphometry**

- L. Inferior frontal g.
- L. temporal pole
- R. insula
- L. middle temporal g.
- L. and R. superior temporal g.

**Structural Imaging**

“PDS subjects showed a small but significant increase in both the number of sulci connecting with the second segment of the right Sylvian fissure and in the number of suprasylvian gyral banks (of sulci) along this segment.”

**Beal et al., 2007**

**Foundas et al., 2001**
• Diffusion Tensor Imaging (DTI)
  - Stutterers: less dense white matter underlying motor cortex
  - In particular laryngeal and tongue representation in left motor cortex
• Conclusion:
  - Suggest disturbed timing of activation in speech relevant brain areas
  - RH overactivation may reflect compensatory mechanism

Sommer et al., 2001
Chang et al., 2008
VBM: Fluent > Stuttering
- Inferior, middle, superior, medial frontal g.
- Pre-post central g.
- Anterior cingulate
- Middle temporal g., supramarginal g.
VBM: Recovered > Persistent
- Cerebellum
- Inferior frontal g.
VBM: Persistent > Recovered
- Cerebellum
- Inferior frontal, precentral
- Inferior parietal, superior temporal g.

Diffusion Tensor Imaging
- Reduced white matter underlying laryngeal motor cortex in persistent stuttering group

Watkins et al., 2008
Foundas et al., 2004

Relationship Planum Temporale asymmetry to altered auditory feedback response

Functional activation changes after learning a bimanual motor sequence

Weerdt et al., 2003
People who stutter may have difficulty:

- Acquiring the necessary skills (motor, sensory, cognitive, ...)
- Automatize the necessary skills
- Applying the necessary skills in demanding situations
- May be due to physiological (functional) and anatomical (structural) differences in cortex and white matter tracts

**CONCLUSIONS**

- Speech of people who stutter is different even when perceptually fluent
- Movement deficiencies are evident in motor and sensory domains
- Behavioural differences are associated with neural activation differences at cortical and subcortical levels
  - Overactivation of primarily sensorimotor areas
  - Overactivation of cerebellar regions
  - Reduced activation of auditory cortex
  - Increased bilateral and/or right hemisphere activation
- Functional differences may be associated with structural differences (grey and white matter)
- Functional differences are task-dependent
  - Fluency enhancing conditions
- Treatment
- Mostly data on adults – initial data on children
- Some of the activation deficiencies may reflect reduced automaticity during execution
- Differences in activation may be related to treatment outcome
FURTHER DIRECTIONS

- Need for research with children
- Gender differentiation
- Neuroimaging of stuttering vs. fluent speech
- Correlating functional with structural differences
- Neuroplasticity
- Exploring effects of different treatments
- Recovery vs. persistence in children
- Relapse in treatment
- Comprehensive multidimensional neural model(s) of stuttering
  - Motor, sensory
  - Language
  - Cognitive, emotional

Thank you!
I'm done talking