Singing the mind electric: 
principles of deep brain stimulation
Morten L. Kringelbach

“I sing the mind electric…”

Linked circuits: reward and motor

Psychosurgery
John F. Fulton (1899-1960) Animal research
Egas Moniz (1874-1955) Leucotomy/Lobotomy Nobel prize 1949
Walter Freeman (1895-1972) Transorbital Lobotomy
Methods of lobotomy

Transorbital lobotomy

Psychosurgery in the US

Early brain stimulation

Pleasure in the brain?

Pleasurable self-stimulation?

Freeman-Watts
Lytton-Fopen
Gratham

Transorbital lobotomy

ECT for anaesthesia
Demonstrating the icepick method

Valenstein (2002)

Wilder Penfield (1891-1976)
Neurological stimulation

James Olds (1922-1976)
Self-stimulation in rats

Robert Heath (1915-1999)
Self-stimulation in humans

The Montreal Star from Friday the 12th March 1954

Pleasure in the brain?

Rats and humans will self-stimulate to the exclusion of all other rewards. Is this pleasurable?

Pleasure in the brain?
Pleasure has to subserve evolutionary imperatives
- Survive and procreate
- Food and sex elicit pleasure
- In social species, social pleasures are very important

Pleasure-elicited reactions
- Conscious and non-conscious components

Pleasure cycles
- Expectation, consummation, satiety, learning

What is pleasure?

Wild-type Zhuang et al (2001) PNAS

DAT knockdown

Positive affect (reward)

Incentive salience

Hedonic impact


Opioid mu agonist: DAMGO microinjections in Nucleus Accumbens (shell)

Peciña and Berridge (2005) Journal of Neuroscience

Pleasure circuits in the rat

Smith and Berridge (2008)
Stimuli: Chocolate milk and tomato juice
Subjective ratings (using visual scale from -2 to +2)
Control measures: Counterbalanced, in-built control for general satiety effects, using tasteless control stimulus
Event-related experiment, random effects, p<0.05 (corr.)

Pleasure electrodes?

Food and subjective hedonic experience

Pleasure of food

The pleasure of touch

Pleasure of drugs
Pleasure of sex

Georgiadis et al. (2006) EJN

Pleasure components

Kringelbach and Berridge (2009) TiCS

Pleasure networks

Kringelbach and Berridge (2009) TiCS

Chronic pain occurs in:
- 5% of post herpetic neuralgia
- 70% of strokes
- 17% of amputees

Pain relief and pleasure

Professor Tipu Aziz
Neurosurgeon & neurophysiologist
Discovered main target (STN) for PD
Recently discovered a new target (PPN) for l-dopa resistant PD
Main target of animal rights extremism

Mr Alex Green
Consultant neurosurgeon

Mr Patrick Schweder

Oxford Functional Neurosurgery

DBS: surgical technique

1. Awake stereotactic exploration for alleviation of chronic pain
   - PM/S/PAG: warmth in area of pain
   - Thalamus: paraesthesia in area of pain
2. One week trialling and recording
3. If efficacious then IPG implantation under general anaesthetic
4. If ineffective electrode removal (Nb. <50 Hz analgesic & >90 Hz hyperalgesic)
Deep brain targets

○ Ventroposterolateral or ventroposteromedial nuclei of sensory thalamus
○ Midbrain periventricular and periaqueductal grey matter

Case series

○ Medically intractable chronic pain
  ▫ Patient selection: suitable for surgery
○ 66 consecutive patients
  ▫ 47 men (71.2%), 19 women (28.8%)
  ▫ Average age: 51 years (26–79y; sd 13y)
  ▫ Average pain duration: 9.9 years (1–48y, sd 8.7y)
○ 10 years: March 1999 – November 2008
  ▫ Single surgeon (Prof. Aziz)
  ▫ Single centre (Oxford)

Visual Analogue Pain Score diaries
McGill pain questionnaire
Quality of life measures
Reductions in medication use
  55% of patients reduced their opiates

Outcomes

McGill pain questionnaire

Implantations by aetiology

Reductions in medication use
55% of patients reduced their opiates
Pain relief with DBS

<table>
<thead>
<tr>
<th>Subjective pain</th>
<th>Pain relief with DBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Hz stim causes pain relief / pleasure</td>
<td>Kringelbach et al. (2007) Nature Review Neuroscience</td>
</tr>
<tr>
<td>90 Hz stim causes much worse pain</td>
<td>Kringelbach et al. (2007) NeuroReport</td>
</tr>
</tbody>
</table>

Electrode parameters

Changing oscillations?

Stimulation-specific subjective changes:
- 20 Hz stim causes pain relief / pleasure
- 90 Hz stim causes much worse pain

Electrode parameters


A resting state hypothesis

Default brain networks change in chronic illness
- E.g. in movement disorders, chronic pain and depression

Deep brain stimulation can re-establish networks
- But ethical considerations are very important

Which nodes of network are most important?

A default baseline network

Beamforming reduces artefacts

Kringelbach and Berridge (2009) TiCS

Litvak et al. (2010)
A neural signature of chronic pain?
Green et al. (2009) Neurology

A more intelligent pacemaker?
Kringelbach and Aziz (2008) Scientific American Mind

DBS in nucleus accumbens

Ventral pallidum and anhedonia

Important to avoid errors of psychosurgery
Careful clinical use
- Only to improve lives of patient
- Full informed consent from patient
- Support from multidisciplinary team
- Continuous monitoring over time
- Restore (but not augment) normal function
- Relieve pain and distress
- Never be used for law enforcement or political purposes

Neuroethics of DBS
Kringelbach and Aziz (2009) JAMA

Hansen, Kringelbach & Salmelin (2010) MEG. An introduction to methods, OUP