Introduction to Medical Imaging (5XSA0)

Medical image acquisition and analysis: Magnetic Resonance Imaging (MRI)

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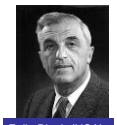
Contents

* **MRI: how does it work?**
  - History
  - Use of MRI
  - Principle of MRI (NMR)
  - Signal acquisition
  - Image reconstruction
* **Autism: fMRI analysis (a clinical study)**

Introduction MRI (1)

* **Short History**
  - Discovery of Nuclear Magnetic Resonance (NMR) in 1947
    - Nobel price in 1952
  - First clinical images in 1977



Felix Bloch (USA)

Edward Mills Purcell (Switzerland)

Raymond Damadian and Larry Minkoff (1978)

Introduction MRI (2)

* **Why use MRI?**
  - Advantages ✓
    - Non-invasive (no radiation)
    - Multiplane without moving the patient
    - Soft tissue contrast
    - Functional images (e.g., real-time)
    - High spatial resolution
  - Disadvantages ✗
    - Expensive
    - Scan duration
    - Contraindication (pacemakers, claustrophobia)
    - Noise

Introduction MRI (3)

* **Clinical application**
  - **Neurology**
    - Structural, functional connectivity
    - Neurodegeneracy, strokes, development disorder, tumor
    - Brain perfusion, angiographie
  - **Cardiology**
    - Real-time heart imaging
  - **Oncology**
    - Breast, liver, prostate, etc.
  - **Soft tissue damage**
    - Caritilage, ligaments, etc.

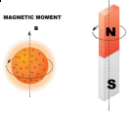
Principle of MRI – (1)

* **General information**
  - Uses magnetic field and radio frequencies
  - Magnetic flux density in Tesla (T)
  - Clinical application 1,5T to 3T (60 000 x the Earth's Magnetic field)
  - Uses the magnetic property of hydrogen (NMR)
  - Applies gradients to the magnetic field to localize the signal

Principle of MRI – (2)

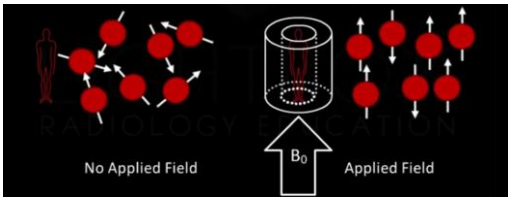
* **Spins**
  - Hydrogen nuclei (protons)
    - 70% of water in a human body
    - Interact with tissues (fat, muscle, etc.)
  - Act as small magnets (charged particles) with magnetic moment

H_2O



Principle of MRI – (3)

* **Spins in a magnetic field**
  - The spins align parallel (low energy) or antiparallel (high energy) to the applied field (B0)



Principle of MRI – (4)

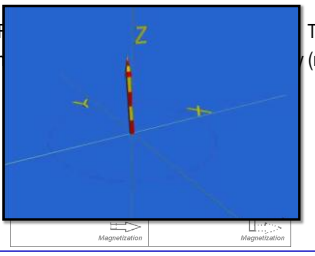
* **Spin precession**
  - Larmor frequency: $f = \gamma \times B_0$

γ = Gyromagnetic Ratio B_0 = Magnetic field Strength

Nucleus	γ_n (10^6 rad s^{-1} T^{-1})	$\gamma_n/(2\pi)$ (MHz T^{-1})
^{1}H	267.513	42.576
^{2}H	41.065	6.536
^{3}He	203.789	32.434

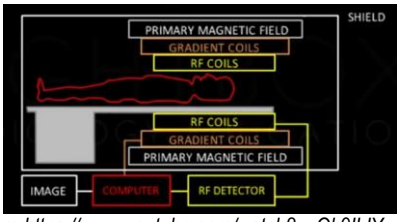
Principle of MRI – (5)

* **Spins excitation and relaxation**
  - RF … T)
  - An… (relaxation)



Signal acquisition – (1)

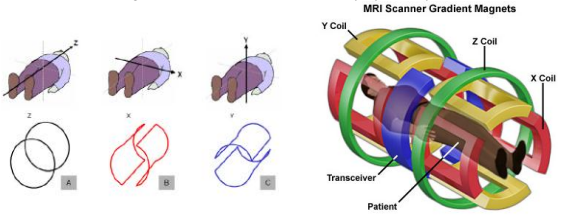
* **MRI machine**



From https://www.youtube.com/watch?v=Ok9ILIYzmaY

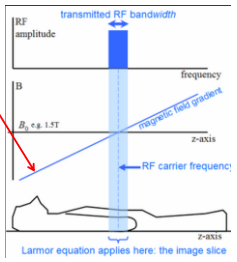
Signal acquisition – (2)

* **Gradient coils**
  - Three gradient coils in each direction (x, y and z)



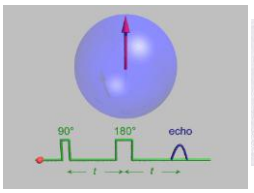
Signal acquisition – (3)

* **Gradient coils**
  - Slice selection gradient (Gz)
  - Frequency encoding (Gx)
  - Phase encoding (Gy)



Signal acquisition – (4)

* **Sequences**
  - Spin-echo Echo-planar imaging sequence



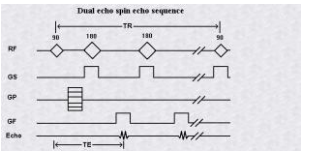
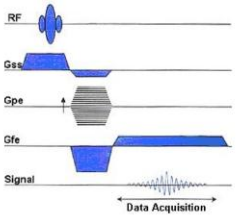


Image reconstruction – (1)

* **Sequences and K-space**
  - E.g, Gradient echo sequence



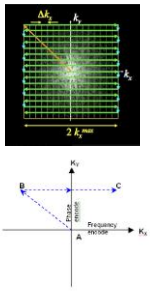


Image reconstruction – (2)

* **Fourier transform to reconstruct the image**

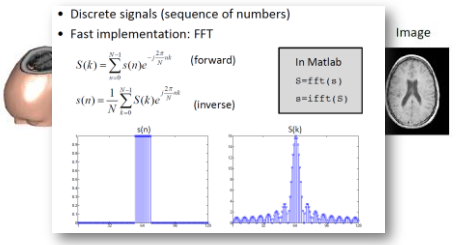


Image reconstruction – (3)

* **Center of the k-space = contrast**
* **External part of the k-space = resolution**

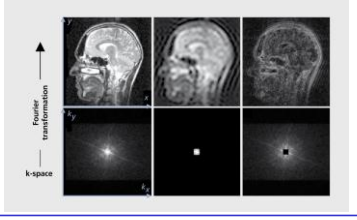


Image contrast (1)

* **T1 and T2**
  - T1: Longitudinal relaxation time (spin-lattice)
  - T2: Transversal relaxation time (spin-spin)
* **TR and TE**
  - TR: repetition time
  - TE: echo time

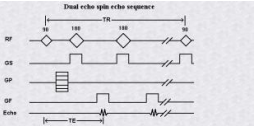


Image contrast (2)

* **Tissue contrast**
  - T1 (m
  - By T1
  - Als

Tissue	T1 (msec)	T2 (msec)
Water/CSF	4000	2000
Gray matter	900	90
Muscle	900	50
Liver	500	40
Fat	250	70
Tendon	400	5
Proteins	250	0.1- 1.0
Ice	5000	0.001

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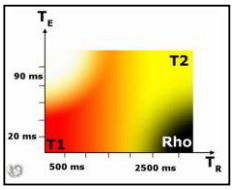
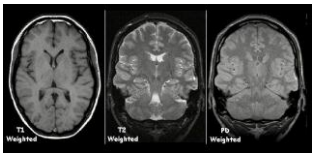
Image Contrast (3)

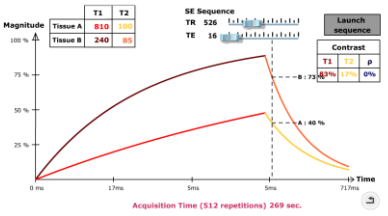
* **T1-, T2, and PD- weighted images contrast**





- Short TR, short TE = T1-weighted
- Long TR, long TE = T2-weighted
- Long TR, short TE = PD-weighted

Image Contrast (4)

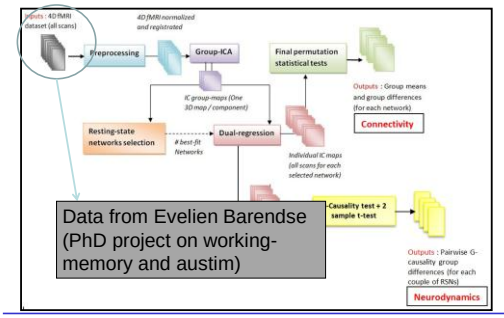


https://www.imaios.com/en/e-Courses/e-MRI/MRI-signal-contrast/Signal-weighting

Autism: fMRI analysis

* **Diagnosis of Autism Spectrum Disorder (ASD)**
  - Not possible only with medical imaging
  - Long process, many psychological tests
* **Literature**
  - Inconsistency in the results (Müller *et al.*, 2011; Tyszka *et al.*, 2013)
  - Not on adolescents with HFA
* **Can we find differences between resting-state networks in adolescents with HFA and controls?**

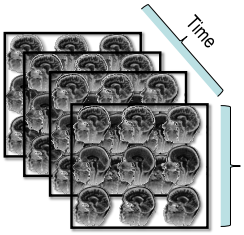
Study on ASD: Design



Data from Evelien Barendse (PhD project on working-memory and austim)

4D fMRI data

* **Blood-Oxygen-Level dependent**



- Desoxygenated blood (dHb)
  - Paramagnetic: inomogeneity
- Oxygenated blood (oHb)
  - Diamagnetic: not susceptible to the magnetic field

Autism: fMRI analysis

* **Diagnosis of autism**
  - Not possible only with medical imaging
  - Long process, many psychological tests
* **Literature**
  - Inconsistency in the results (Müller *et al.*, 2011; Tyszka *et al.*, 2013)
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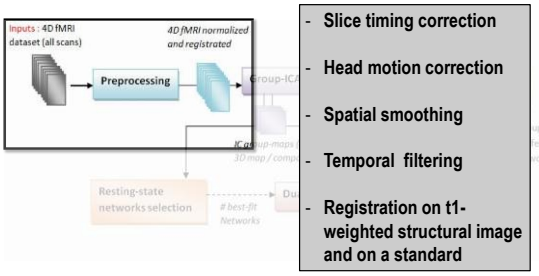
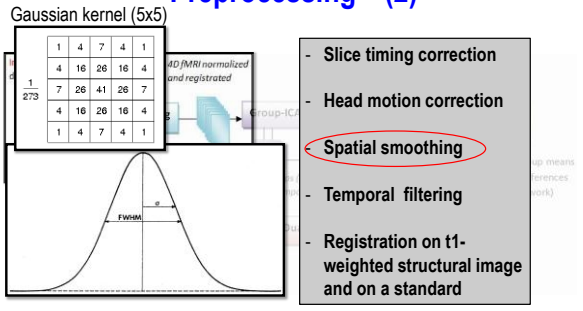
Preprocessing – (1)



- Slice timing correction
- Head motion correction
- Spatial smoothing
- Temporal filtering
- Registration on t1-weighted structural image and on a standard

Preprocessing – (2)



- Slice timing correction
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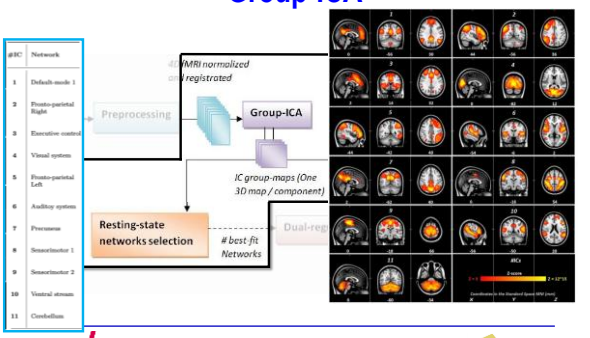
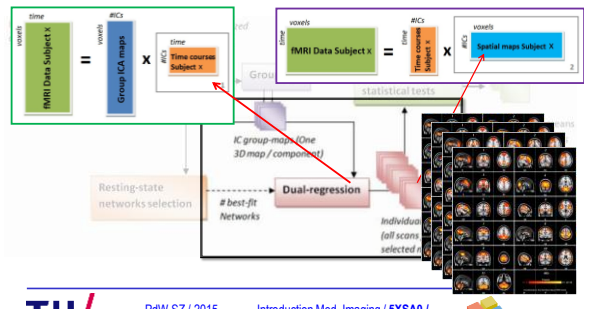
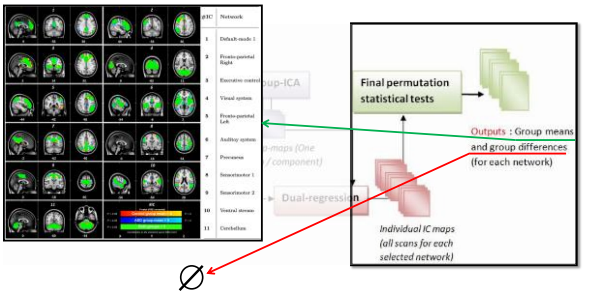
Group-ICA



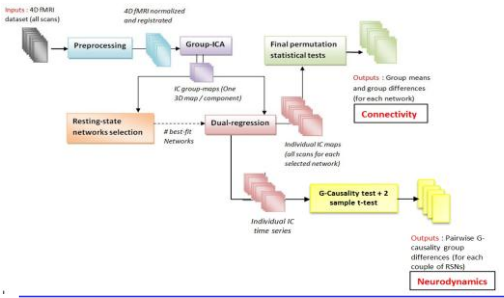
Network selection & individual IC maps



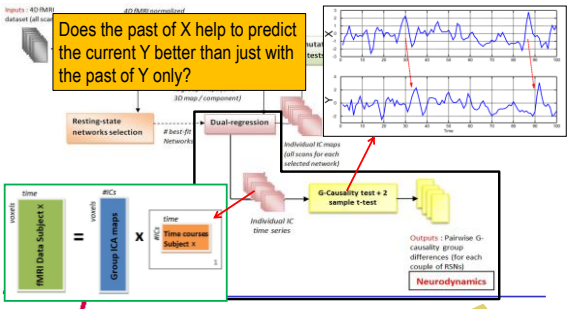
Spatial connectivity results



Temporal neurodynamics

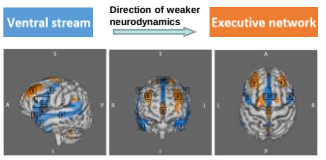


Granger causality



Neurodynamics conclusion

- **Weaker directed causality from ventral stream to executive network in HFA**
- **Only in the second resting-state scan**
- **Probably triggered by the preceding cognitive task**



(Bernas *et al., ready for submission)*

- **Networks involved: executive and emotion-related cortices**
- **Processes of these networks: known as weak points in ASD**

MRI Conclusion

- **MRI is used for different clinical applications**
  - brain, heart, soft tissues, tumors
- **Uses the principle of NMR**
  - spin magnetizations
  - RF pulses and spin relaxations
- **Images reconstructed with Fourier transform**
- **General image preprocessing used for analysis**
  - segmentation, smoothing, temporal filtering, registration