Meditation and brain activity

NeuroMath
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Overview

- Meditation as balancing the mind
- Theoretical background
- FSL Wizard
  - MATLAB script
  - Development process
  - Program functions
  - Example results of analyses
- Future?
Meditation

• Achieving a balanced state of mind:
  – ”control of fluctuations of the mind”.
  – ”still the fluctuations of the mind”.
  – ”then the mind (the self) abides in itself. Consciousness can abide in its very nature”.
  – At other times ”the self (mind, awareness) identifies itself with the fluctuating patterns of consciousness”.
  – Patanjali: *Yoga Sutras*

• Meditation compared to sensori-motor balance (eg skiing, standing, walking, shooting at a target).
  – Objectively measurable indicator of balance?
Balance

• Investigations of infants learning to sit and walk
  – At first uncontrolled variability in posture and movement
  – Gradual achievement of some stability in posture by constraining degrees of freedom in limb movements
  – Later increasing stability in posture by increasing degrees of freedom in limb movements to compensate for momentary disturbances.

• Studies of marksmanship reveal development of synergistic compensatory limb movements in experts

• Measurement of behavioral achievement of stability
  – No such measurement in this investigation of meditation
  – (but see Guo & Pagnoni 2008, Neuroimage).

• Measurement of neural processes
  – Possible differences between resting and meditating?
Theoretical background

• Lundervold’s illustration of the mathematical and scientific roots of emergence etc.
  – Cyprus Workshop nov. 2009 Nonlinear Biomedical Physics (2010) 4: supplement
  – Psychology not mentioned

• Some psychological theories are compatible with dynamical theories in natural sciences
  – Russian theory of activity and Cultural Historical Psychology
  – Gibsons Ecological Psychology
  – Dynamical systems, Synergetics, Complex adaptive systems etc.
Activity theory
An alternative to stimulus-response reflex theory

The basic schema of stimulus – response theory:

Stimuli do not ”cause” responses, they may perturb ongoing activity. Ongoing activity usually causes stimulation of sensory organs. (cf Dewey 1896: behaviour is not reflexes, but ”coordinations”)

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Activity theory
An alternative to stimulus-response reflex theory

Activity
flow of information during interacting with objects in the environment
Dimensions of mind in activity

- **Activity**
  - Motive = need + potentially need satisfying object

- **Action**
  - Goal = intended result of activity (Sensory parameters of goal state)

- **Operation**
  - Form of activity given the conditions of realisation (external and internal)
Functional systems stage 1
Afferent synthesis

OR: orienting reaction
EA: environmental afferentiation
ME: memory
RF: collaterals of reticular formation
AA: activating afferentiation
MO: motivation

Anokhin (1969)
Functional systems stage 2
Execution

OR: orienting reaction
EA: environmental afferentiation
ME: memory
RF: collaterals of reticular formation
AA: activating afferentiation
MO: motivation

Anokhin (1969)
Functional systems stage 3
Achievement or change of goal

OR: orienting reaction
EA: environmental afferentiation
ME: memory
RF: collaterals of reticular formation
AA: activating afferentiation
MO: motivation

Anokhin (1969)
Ecological flow/form/time

Dynamical systems, synergetics, self organisation in complex adaptive systems, etc etc

Functional systems theory  Activity theory, cultural historical psychology

ecological psychology,

Metabolic processes in the organism
Psychological regulation of organismic activity as realised by functional brain systems
Movement of organism and its limbs in material situation
Dynamic patterns of multimodal sensory stimulation on sensory receptors
Ecological layout and events in the world including cultural historical forms
Meditation investigated with fMRI

- **Goal:** Characterisation and visualisation of dynamics of brain activity during:
  - Meditation.
    - On-off
    - Continuous
  - Baseline-resting state.
  - Fingertapping.
  - (… and in general).
- **Assume:** Experimental tasks create perturbations of continuously ongoing neural processes (cf. baseline – resting state; default mode).
- **Questions:**
  - Extent to which IC’s represent ”Standard” RSN components?
  - Different temporal relationsshifts among IC’s during tasks?
  - Varying patterns of correlation and causation during tasks?

- **Concatenation group analysis with FSL**
  - http://www.fmrib.ox.ac.uk/fsl/
Output from ICA with FSL

• Task related sets of individual process components,
  – anatomical areas in which variations in BOLD signal follow a common pattern (time series)
    • during fingertapning, resting, meditation on-off and continuous meditation.

• ”FSL Wizard” postprocessing utilise:
  – Thresholded maps of component localisation
  – IC time series for eigenvector and individual subjects
  – IC Fourier power spectrum for eigenvector
  – Realignment parameters for individual subjects
FSL Wizard
FSL Wizard

- MATLAB script running on Linux
- Control FSL analyses
  - Selecting designs to analyse
  - Selecting scans based on a number of criteria, eg.
    - Highres. Anatomical scan available
    - Subject also involved in other tasks etc.
FSL Wizard

- FSL analysis
- Postprocessing of IC information
- IC time series correlation analysis
- Anatomical comparison

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FSL Wizard

• Task list
  – Queue of analyses to perform
  – Keeps track of performed analyses
    • Unique time stamp
  – Easy to repeat (modified) analyses
FSL Wizard

- FSL Analysis and postprocessing options (checkboxes)
  - Anatomical identification of IC’s
  - Correlation of IC time series with realignment parameters
  - Correlation of IC’s (real subjects)
  - Correlation of IC Eigenvectors
  - Comparison of IC anatomies (Dist_3d)
  - IC time series correlation options
    - Phase shifting +/- 1-5 phases (scan)
    - Travelling window (5 phases- n phases)
    - Level of significance for correlation
    - No of phases in epochs (eg 13)
  - Change order of IC’s in analysis

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FSL Wizard

- **Anatomical identification of IC’s**
  - Local maxima – MNI- Talairach space - Talairach daemon
  - Total cluster voxels – Talairach daemon
  - Conversion from NiFTI via MNI to Talairach space.

- **Anatomical comparison across components across scans**
  - Change order of IC’s according to a predefined functional ordering
  - Minimal distance between local maxima
  - Comparison of voxels involved in IC’s
Anatomical comparison

- Functional ordering and comparison across scans
  - is important for interpretation of
- IC time series correlation comparison across different scans
  - Ideally components should be identical?
  - Or differences may have functional importance?
- Comparison to standard RSN network components would be preferable
  - Beckmann et al (2005); Smith et al. (2009)
Common RSN components

a) Primary visual cortex.

b) Secondary visual cortex.

c) Auditory and higher order cognitive cortex. Temporal, Thalamus.

d) Sensory-motor cortex.

e) Default mode network: Posterior cingulum, vmPFC, PTO.

f) Executive control: ACC, dlPFC

g) dlPFC, ACC, right parietal cortex (dorsal visual route).

h) dlPFC, ACC, left parietal cortex (dorsal visual route).

RSN reference IC’s

a) Primary visual cortex.

b) Secondary visual cortex.

c) Auditory and higher order cognitive (Temporal, Thalamus).

d) Sensory-motor cortex.

e) Default mode network:

f) Executive control

g) Spatial attention; dIPFC, right parietal.

h) Spatial attention; dIPFC, left parietal cortex
Anatomical identification of RSN’s

Functional reordering

IC’s in different scans representing common RSN’s and artefacts. The assigned IC numbers from FSL analysis are given. Best fit references are marked by *.
Categorisation is based on visual inspection of components, compared to examples given in Beckmann et al 2005, and Smith et al 2009.

<table>
<thead>
<tr>
<th>RSN</th>
<th>Finger</th>
<th>Rest 1</th>
<th>O-o 1</th>
<th>Cont</th>
<th>O-o 2</th>
<th>Rest 2</th>
<th>O-o 1-2</th>
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<td>12</td>
<td>30*</td>
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<td>9</td>
<td>12</td>
<td>11</td>
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<td>8</td>
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<td>10*</td>
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<td>3</td>
<td>13</td>
<td>6</td>
<td>9</td>
<td>5</td>
</tr>
</tbody>
</table>

IC’s 17 16 14 38 17 13 16 16
The selection of components (IC’s) representing RSN’s based on visual inspection. In general this leads to acceptable results, but for a few instances Table show relative proportion (%) of overlapping voxels in components, as well as average rank of comparisons (all IC’s compared) Selection of components only on the basis of 1. rank calculated overlap is not viable. Visual inspection, or maybe combination with neuroanatomical information is necessary.

<table>
<thead>
<tr>
<th>All scans</th>
<th>RSN components</th>
<th>Anatomical overlap in %</th>
<th>2011-05-17</th>
<th>17:52</th>
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<tr>
<td></td>
<td>finger overlap</td>
<td>rank</td>
<td>resting 1 overlap</td>
<td>rank</td>
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<td>a</td>
<td>68</td>
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<td>56</td>
<td>1.4</td>
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<td>65</td>
<td>1.1</td>
<td>57</td>
<td>1.0</td>
</tr>
<tr>
<td>c</td>
<td>43</td>
<td>1.0</td>
<td>31</td>
<td>3.0</td>
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<tr>
<td>d</td>
<td>37</td>
<td>2.0</td>
<td>72</td>
<td>1.0</td>
</tr>
<tr>
<td>e</td>
<td>57</td>
<td>1.0</td>
<td>35</td>
<td>2.4</td>
</tr>
<tr>
<td>f</td>
<td>10</td>
<td>8.4</td>
<td>65</td>
<td>1.3</td>
</tr>
<tr>
<td>g</td>
<td>62</td>
<td>1.0</td>
<td>57</td>
<td>1.0</td>
</tr>
<tr>
<td>h</td>
<td>42</td>
<td>1.3</td>
<td>44</td>
<td>1.3</td>
</tr>
<tr>
<td>ventricle</td>
<td>66</td>
<td>1.0</td>
<td>66</td>
<td>1.0</td>
</tr>
<tr>
<td>orbital</td>
<td>80</td>
<td>1.0</td>
<td>75</td>
<td>1.0</td>
</tr>
</tbody>
</table>

RSN avg |
46.7  | 2.1  | 52.0  | 1.6  | 62.2  | 1.1  | 32.9  | 1.7  | 52.6  | 1.7  | 51.1  | 1.3  | 65.1  | 1.1  | 59.5  | 1.3  | 52.8  | 1.5  | 1.25 |

Artefakt avg |
73.0  | 1.0  | 70.6  | 1.0  | 68.3  | 1.0  | 44.4  | 1.6  | 72.0  | 1.0  | 57.4  | 1.1  | 84.6  | 1.0  | 68.3  | 1.0  | 67.3  | 1.1  | 1.1  |

Artefakt std |
15.7  | 0.0  | 13.7  | 0.0  | 15.1  | 0.0  | 13.8  | 0.7  | 12.1  | 0.0  | 10.7  | 0.3  | 9.6   | 0.0  | 20.5  | 0.0  | 18.1  | 0.3  | 0.3  |
Anatomical identification of RSN e

<table>
<thead>
<tr>
<th>Anatomical label</th>
<th>reference (rest 2 IC 8)</th>
<th>Average</th>
<th>Standard deviation</th>
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<tbody>
<tr>
<td>No of voxels in IC</td>
<td>4138</td>
<td>3152</td>
<td>901</td>
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<tr>
<td>Left hemisphere</td>
<td>1810</td>
<td>1389</td>
<td>337</td>
</tr>
<tr>
<td>Right hemisphere</td>
<td>1417</td>
<td>1160</td>
<td>332</td>
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<tr>
<td>Frontal lobe</td>
<td>728</td>
<td>496</td>
<td>206</td>
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<tr>
<td>Parietal lobe</td>
<td>512</td>
<td>347</td>
<td>169</td>
</tr>
<tr>
<td>Temporal lobe</td>
<td>1084</td>
<td>746</td>
<td>244</td>
</tr>
<tr>
<td>Occipital lobe</td>
<td>239</td>
<td>249</td>
<td>26</td>
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<tr>
<td>Limbic lobe</td>
<td>519</td>
<td>478</td>
<td>103</td>
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<tr>
<td>Post.cingulum</td>
<td>214</td>
<td>209</td>
<td>16</td>
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<tr>
<td>Sublobar</td>
<td>124</td>
<td>213</td>
<td>78</td>
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<tr>
<td>Thalamus</td>
<td>8</td>
<td>42</td>
<td>40</td>
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</table>
IC time series correlation

• Realignment
  • IC time series correlation with realignment parameters.
  • Assessment of the extent to which IC represent movement artefacts or psychological factors

• Correlation with experimental designs
  • Indication for task relevance

• Mutual correlation

• 5-phase (17.5 sec.) interval
  • Improbable that IC’s should remain in constant pattern of correlation during a complete scan

• Time shifted correlations
  • Indicator for causal relationships
Example component time series

RSN time series correlation with design Eigenvectors

<table>
<thead>
<tr>
<th>RSN</th>
<th>Fingertapping</th>
<th>Resting state 1</th>
<th>Meditation on-off 1</th>
<th>Continuous meditation</th>
<th>Meditation on-off 2</th>
<th>Resting state 2</th>
<th>Meditation on-off 1+2</th>
<th>Resting state 1+2</th>
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</thead>
<tbody>
<tr>
<td>a)</td>
<td>-0.39</td>
<td>-0.43</td>
<td>+0.75</td>
<td>-0.67</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b)</td>
<td>-0.39</td>
<td>-0.43</td>
<td>-0.75</td>
<td>-0.67</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c)</td>
<td>-0.60</td>
<td>+0.22</td>
<td>-0.63</td>
<td>+0.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d)</td>
<td>+0.82</td>
<td>+0.50</td>
<td>+0.81</td>
<td>+0.77</td>
<td></td>
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<td>e)</td>
<td>-0.85</td>
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<td>-0.69</td>
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<td>f)</td>
<td>-0.60</td>
<td>+0.68</td>
<td>+0.62</td>
<td></td>
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<td>g)</td>
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<td>-0.61</td>
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<td>h)</td>
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<td>+0.69</td>
<td>+0.37</td>
<td>-0.56</td>
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</tbody>
</table>

Correlations are significant at p<0.001 (uncorrected for multiple comparisons).
Continuous meditation df= 275; all other tasks, df=75.

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Correlations between components

Eigenvalues

Correlations are significant at p<0.001 (uncorrected for multiple comparisons).

Continuous meditation df= 275; all other tasks, df= 75.

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Correlations between components

Real subjects

Fingertap | Baseline 1 | Medi.on-off 1 | Cont.Medi. | Medi.on-off 2 | Baseline 2

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Correlations between components
Eigenvectors, 17.5 sec. intervals

Fingertap. Number of 17.5 sec. Intervals with positive correlations between RSN components (p<0.001).

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
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Fingertap. Number of 17.5 sec. Intervals with negative correlations between RSN components (p<0.001).

<table>
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<td>18</td>
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</table>

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Correlations between components

17. 5 sec. Intervals

Continuous meditation
Participants and support

- Experimental participants.
- Anne Sophie Jørgensen, Jørgen Høher, Rients Ritskes (meditation teachers).
- Colleagues assistants, discussants
  - Lektor Hans Støldkilde-Jørgensen (MR Research Center, Aarhus University hospital, Skejby Sygehus).
  - Pernille Bruhn, Jakob Erland, Johannes Damsgaard Bruhn, Mark Forsnæs, Anders Chr. Green, Tue Hartmann, Jens Mammen, Cecilie Møller, Bo Sommerlund, Kirstine Sonne Berg, Freya Winther, (PIAU).
  - Eva B. Vedel Jensen, Niels Væver Hartvig, Thordis Thorarinsdottir (Department of Statistics).
  - Many unmentioned colleagues and students.
  - COST BM0601 Neuromath
- Økonomisk støtte
  - Humanistisk forskningsråd (Rococo projektet)
  - Aarhus Universitets Forskningsfond.
Literature

Activity theory, Functional systems, Ecological psychology, Dynamical systems

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- May be retrieved from: [http://www.marxists.org/archive/leontev/](http://www.marxists.org/archive/leontev/)


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