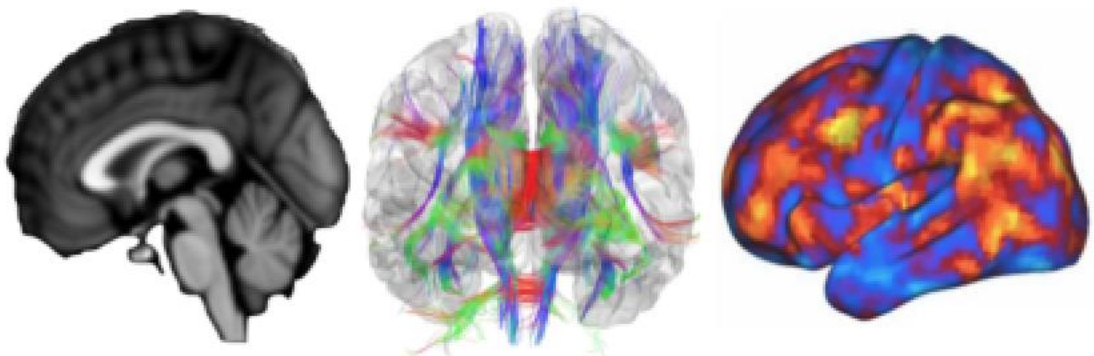


Welcome!

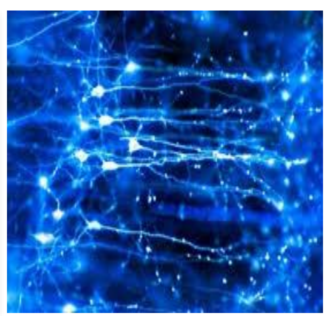
NICUM

1. course overview & ressources
2. facility, informed consent, accidents, security training, artifacts
3. Structural MRI, volume, surface, cortical thickness
4. Neuro-Query, big data, Pilot studies, Individual subjects
5. Pipelines, transparency, Open Science

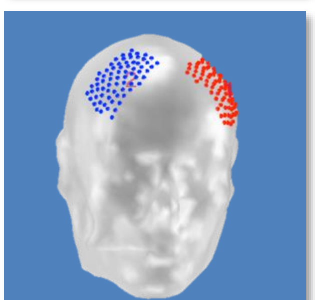
NICUM

From Scans to Brain: MRI Basics and Safety Issues

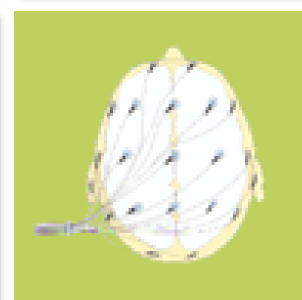
Daniel Keeser
Research group "Neuromodulation and Multimodal NeuroImaging"
Dept. of Psychiatry and Psychotherapy, University Hospital (LMU), Munich, Germany
NeuroImaging Core Unit Munich (NICUM), University LMU, Munich, Germany





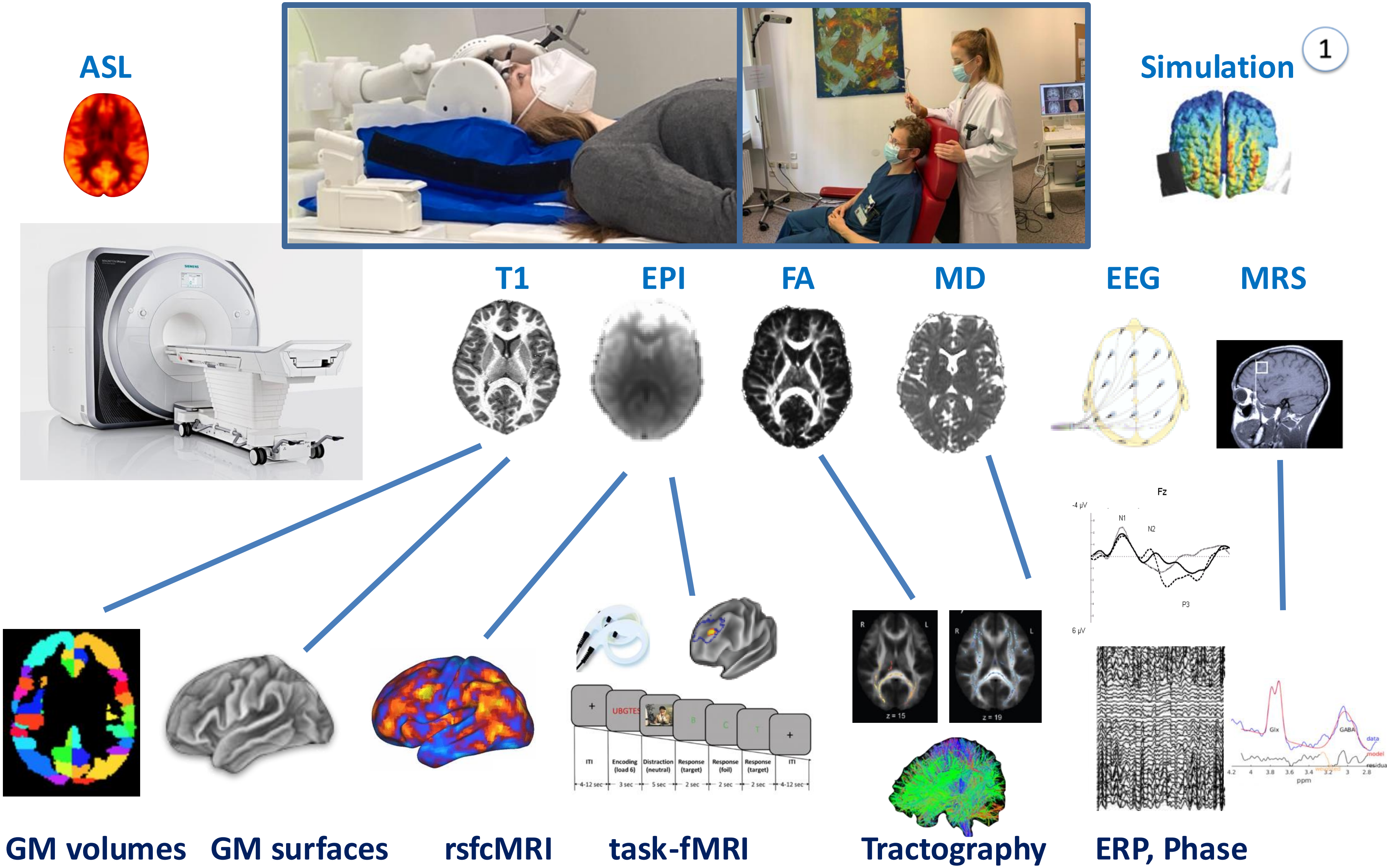
OSC
LMU Open Science Center

GCBS
Gefördert vom
Bundesministerium für Bildung und Forschung
DLR Projektträger

Resources provided (subsequent deepening)

https://drive.google.com/drive/folders/1uSG6F7pJ6EFNODxoUtUSgzsfY_IHwd9q?usp=drive_link

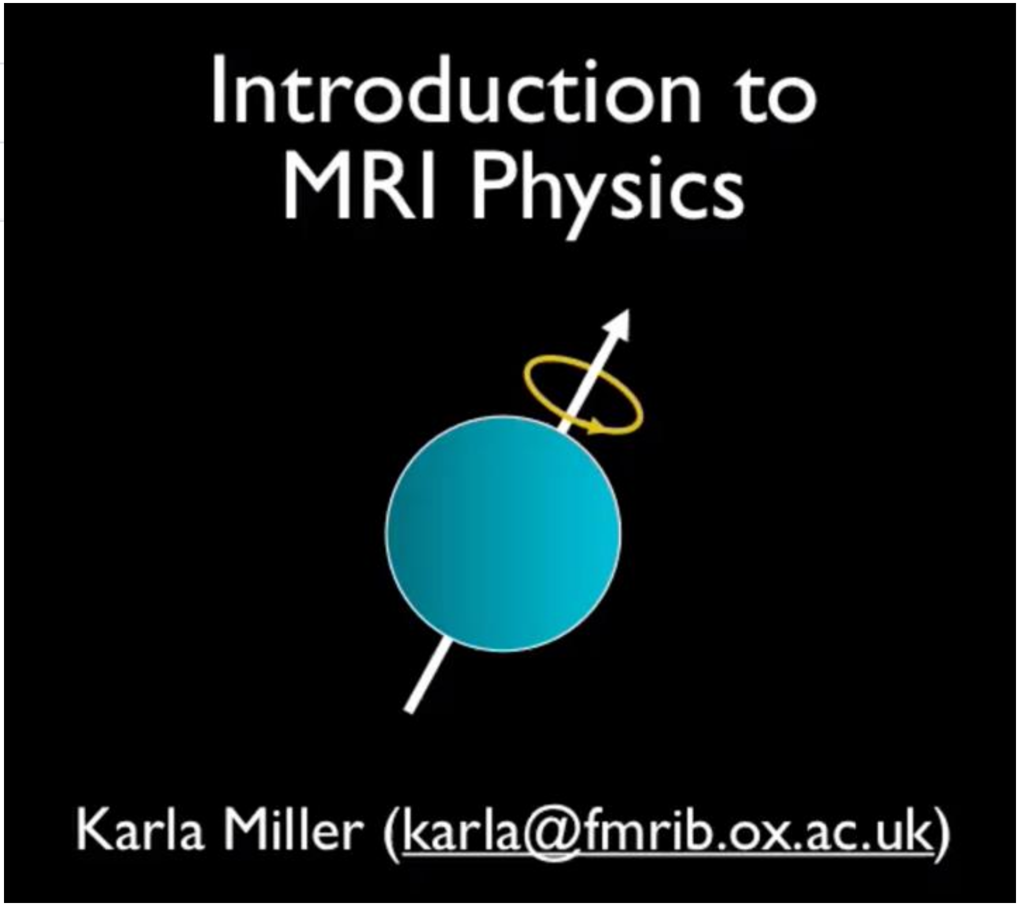


Keeser et al., *J Neuroscience 2011*
Keeser et al., *NeuroImage 2011*
Palm*, Keeser* et al., *Schizophrenia Bulletin 2016*
Chang et al., *NeuroImage 2024*

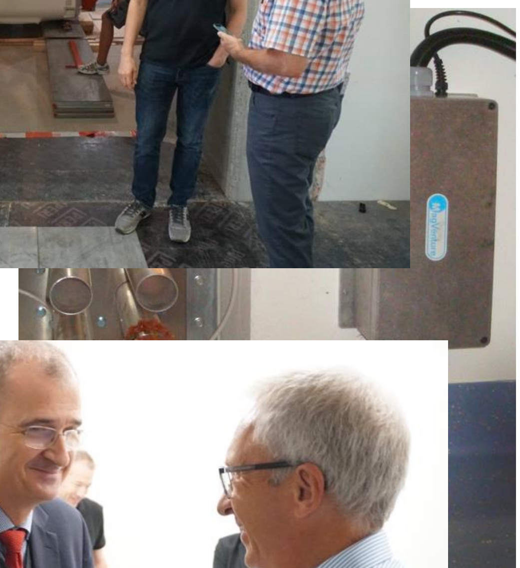
Wörsching et al., *NeuroImage 2017*
Wörsching et al., *Brain Stimulation 2018*
Bulubas et al., *Brain Stimulation 2019, 2022*
Mizutani-Tiebel et al., *NeuroImage Clinical 2022*

Physics of MRI

- 1_Intro_to_MR_physics.mp4
- 2_ImageFormation.mp4
- 2a_Basic_Maths_Week2Lecture2.mp4
- 3_Pulse_Sequences.mp4
- 4_Contrast_Manipulation_2014.mp4



MRI facility – arrival of the scanner 2019



2024: 4th year of NICUM

LMU

NICUM

HISTORY

2015

Roadmap NIMG Research at LMU:

- 2 x 3T scanners (2017)
- Animal MRI (2018)
- 7T scanner (2022)

2016

- Proposal for research scanner submitted to DFG
- grant awarded by DFG/Bavarian state (2,45 Mio. €)

2017

- Sharing responsibilities LMU/KUM
- construction costs: 660,000€ KUM,
  1 Mio. € LMU

2018/ 2019

- 2018:Construction planning and construction work
- end of 2019: scanner transferred to KUM/LMU

2020

8/2020: Release of the NICUM research scanner
Real start 1/2021

MRI facility – rooms/location

https://www.en.nicum.uni-muenchen.de/

Current Research Topics

ELSEVIER
Biological Psychiatry
Available online 27 April 2024
In Press, Journal Pre-proof ⓘ What's this?

Archival Report

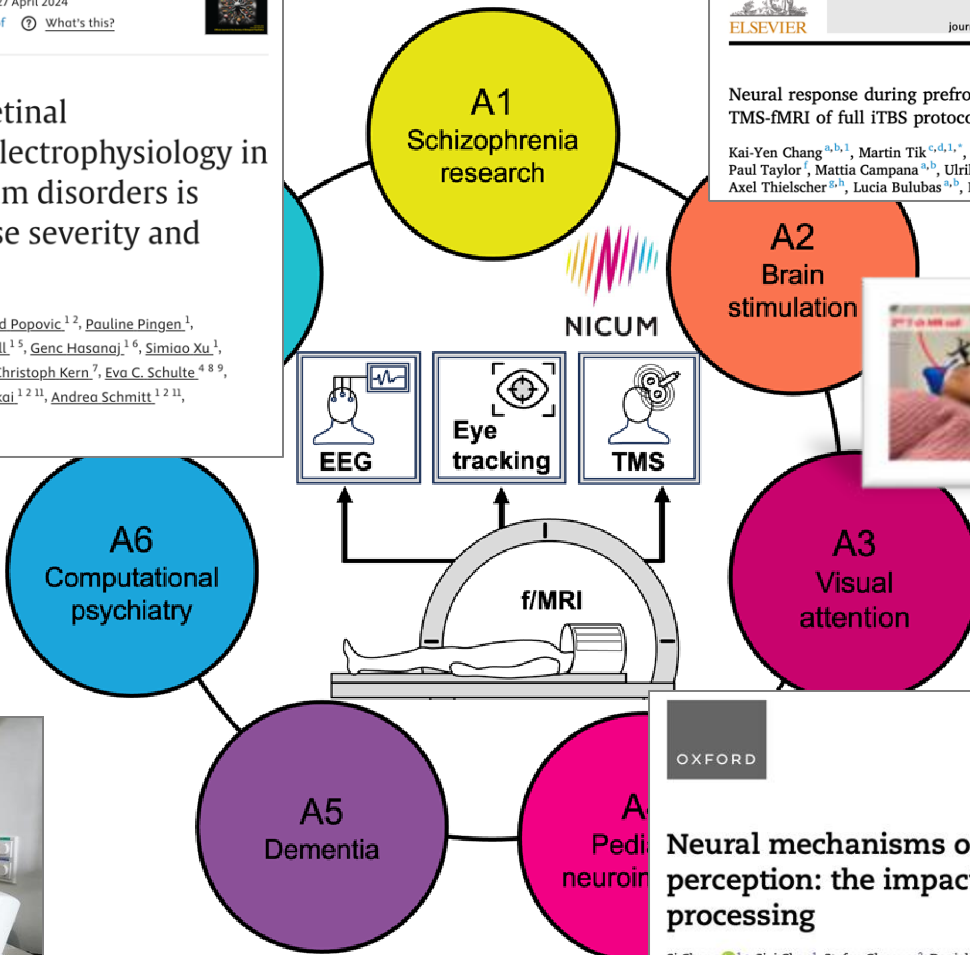
Signature of altered retinal microstructures and electrophysiology in schizophrenia spectrum disorders is associated with disease severity and polygenic risk

Emanuel Boudriot[1 2 *], Vanessa Gabriel[1 *], David Popovic[1 2], Pauline Pingen[1], Vladislav Yakimov[1 3], Sergi Papiol[2 4], Lukas Roell[1 5], Genc Hasanaj[1 6], Simiao Xu[1], Joanna Moussiopoulou[1], Siegfried Priglinger[7], Christoph Kern[7], Eva C. Schulte[4 8 9], Alkomiet Hasan[10 11], Oliver Pogarell[1], Peter Falkai[1 2 11], Andrea Schmitt[1 2 11], Benedikt Schworm[7]
CDP Working Group[12610]

NeuroImage 291 (2024) 120596
Contents lists available at ScienceDirect
NeuroImage
journal homepage: www.elsevier.com/locate/ynimg
ELSEVIER

Neural response during prefrontal theta burst stimulation: Interleaved TMS-fMRI of full iTBS protocols

Kai-Yen Chang[a,b,1], Martin Tik[c,d,1,*], Yuki Mizutani-Tiebel[a,b], Anna-Lisa Schuler[e], Paul Taylor[f], Mattia Campana[a,b], Ulrike Vogelmann[a], Barbara Huber[a], Esther Dechantsreiter[a], Axel Thielscher[g,h], Lucia Bulubas[a,b], Frank Padberg[a,b,1], Daniel Keeser[a,b,1,*]



OXFORD
Cerebral Cortex, 2023, 1–14
https://doi.org/10.1093/cercor/bhad453
Original Article

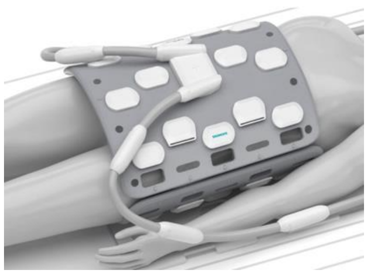
Neural mechanisms of sequential dependence in time perception: the impact of prior task and memory processing

Si Cheng[1,*], Siyi Chen[1], Stefan Glasauer[2], Daniel Keeser[3], Zhuanghua Shi[1,3]

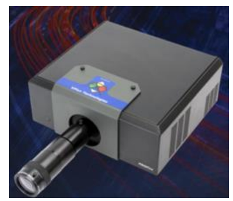
MRI facility - Equipment

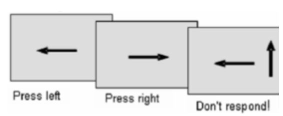
Head and body coils





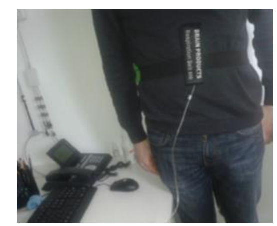
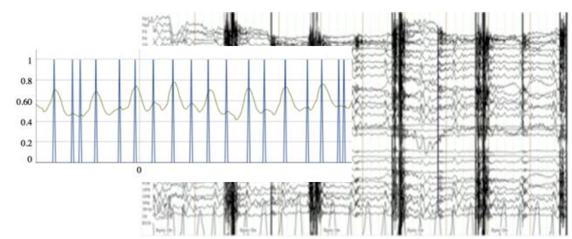

Video projector fMRI



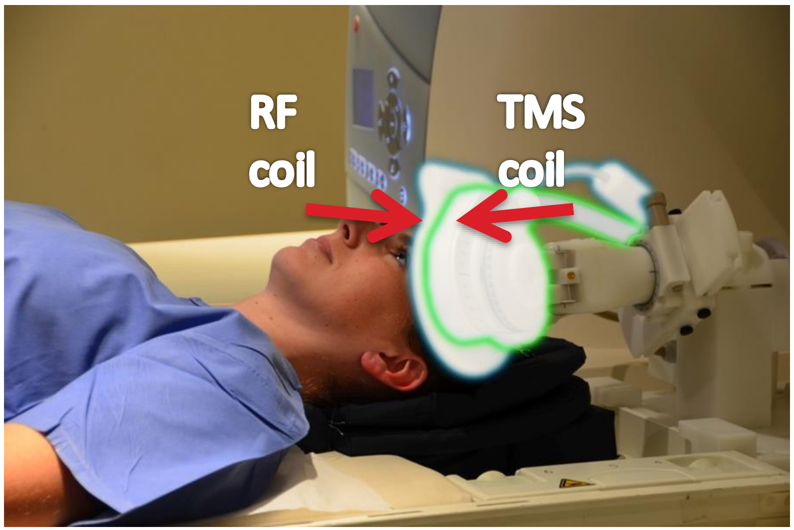
Simultaneous EEG/ECG/respiration



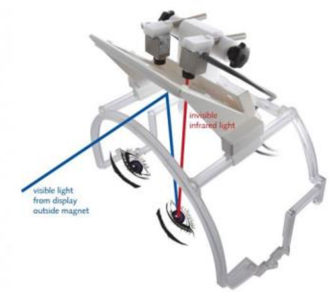




MRI facility - Equipment

Neuronavigated TMS inside MRI



Eye Tracking



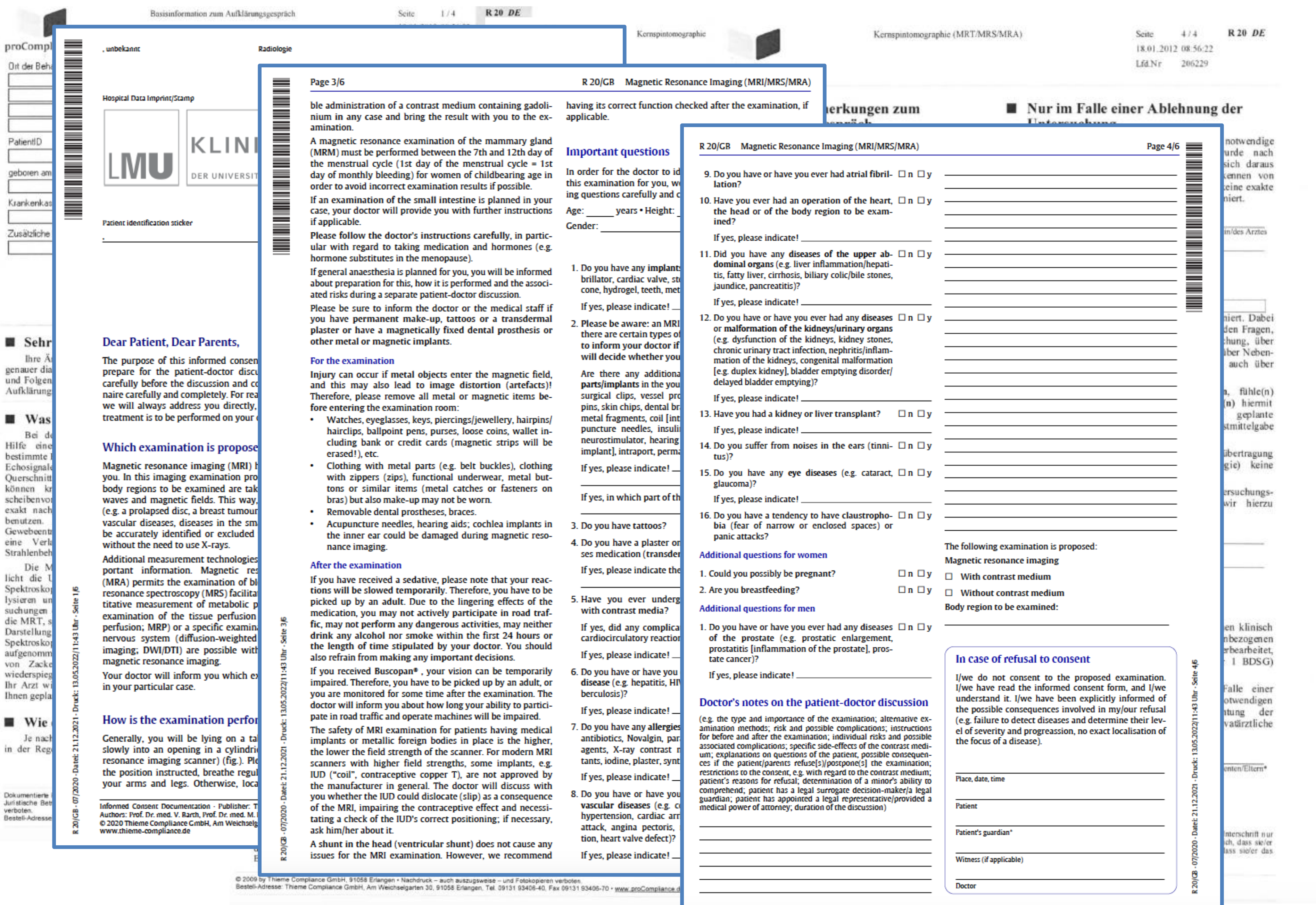
TMS

Contrast agent pump

MR safety

1. Do you have an electronic implant or device (e.g. cardiac pacemaker, implanted defibrillator, neurostimulator, insulin pump)?

MR safety – Informed consent



Neuroradiolog

Kurzbefund für Studien-MRT
Bitte an sek.neurorad@med.lmu.de schicken.

Von verantwortlichem*r Mitarbeiter*in auszufüllen:

Probanden ID/Name Studienpatient*in: NIMG_course_20

MRT vom (Datum der Untersuchung):

Studie: multimodal Neuroimaging Course 2021

Verantwortliche*r Wissenschaftler*in: Daniel Keeser

E-Ma

Vom*n N

Vorliegen

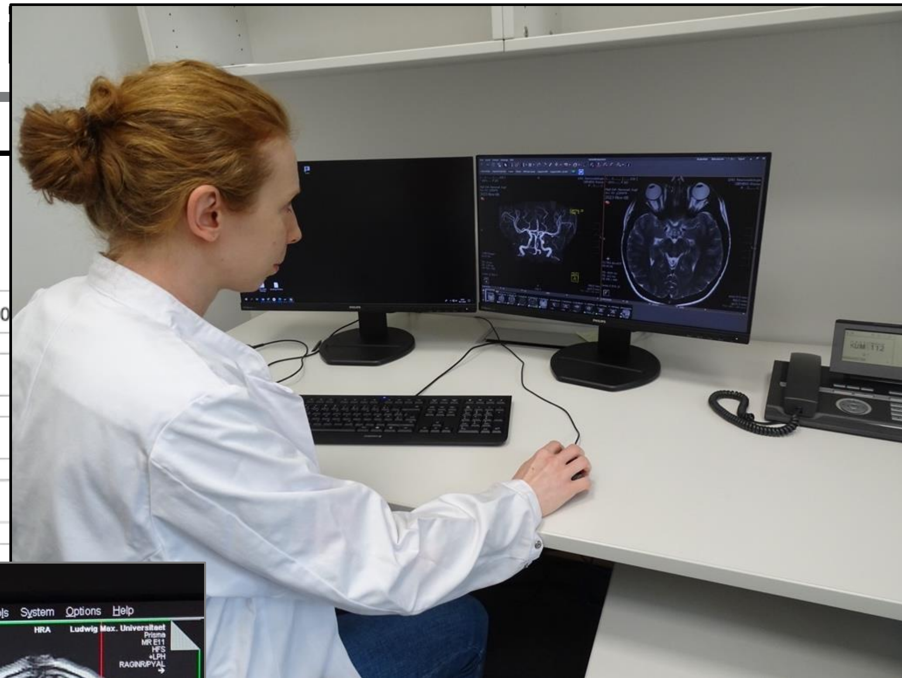
Befunde:

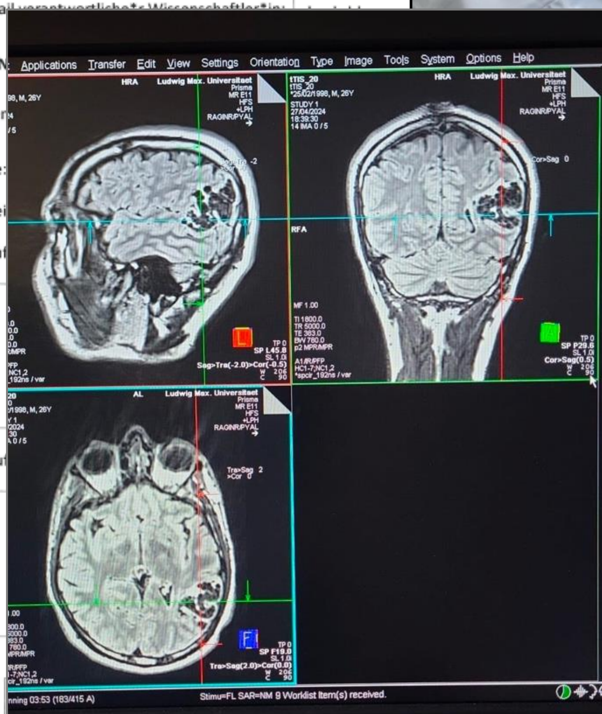
Kei

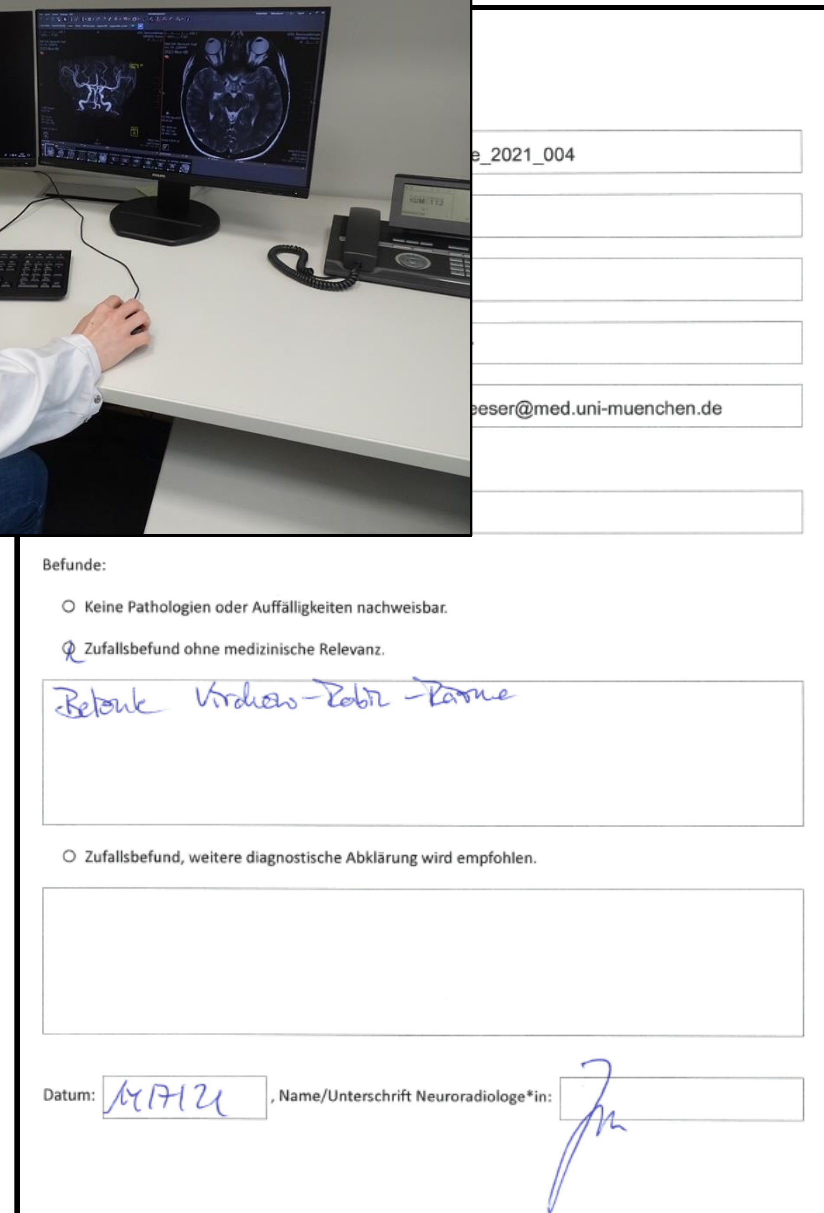
Zu

Zu

Datum:






e_2021_004

eeser@med.uni-muenchen.de

Befunde:

○ Keine Pathologien oder Auffälligkeiten nachweisbar.

○ Zufallsbefund ohne medizinische Relevanz.

Betont Virchow-Robin-Räume

○ Zufallsbefund, weitere diagnostische Abklärung wird empfohlen.

Datum: 14.7.21, Name/Unterschrift Neuroradiologe*in:

MR safety – dangers

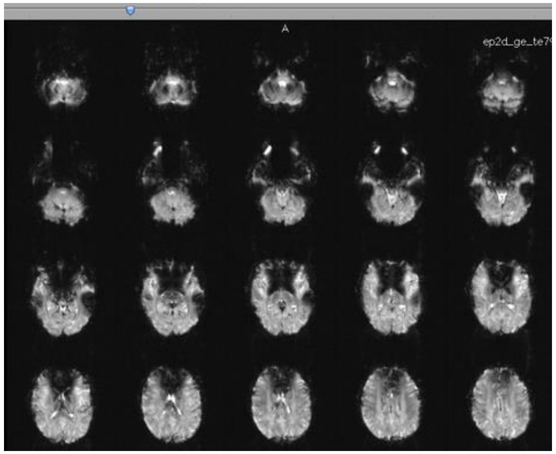
Risk through magnetic fields:

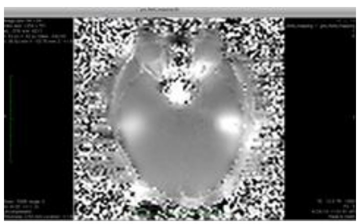
- Static magnetic fields (metal objects pulled)
- Moving objects in static field (induction, heat)
- HF-fields, gradients (heat, induction, nerve stim)

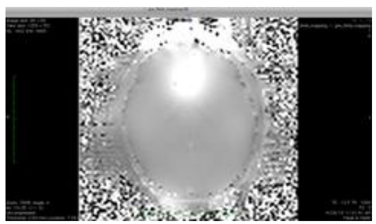
MRI safety training

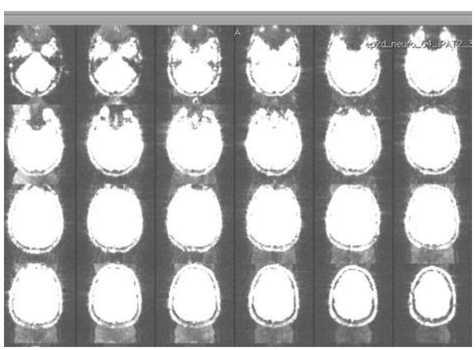
This lecture must be attended at least once a year (signature required).

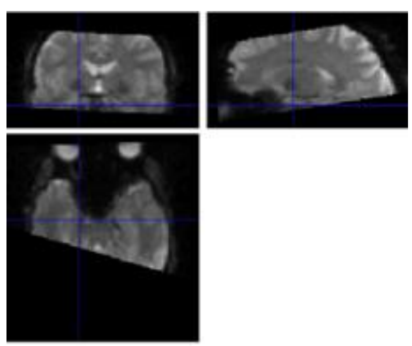
MR artifacts





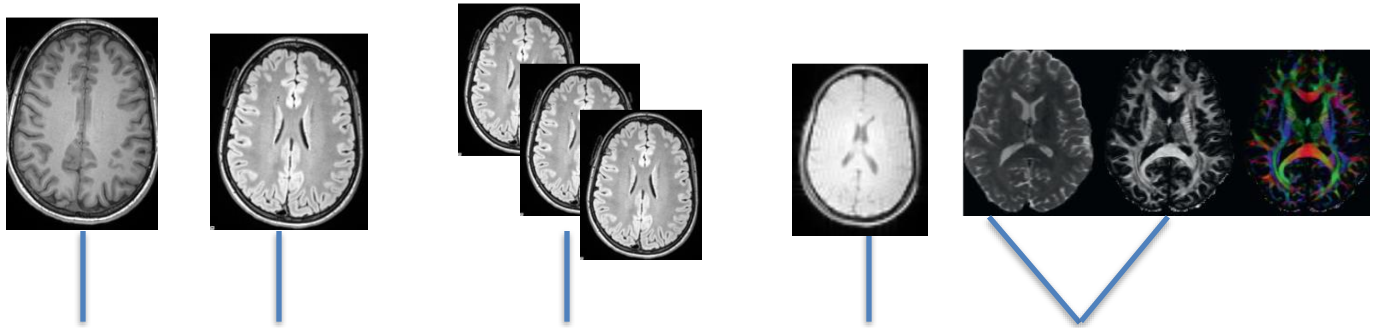






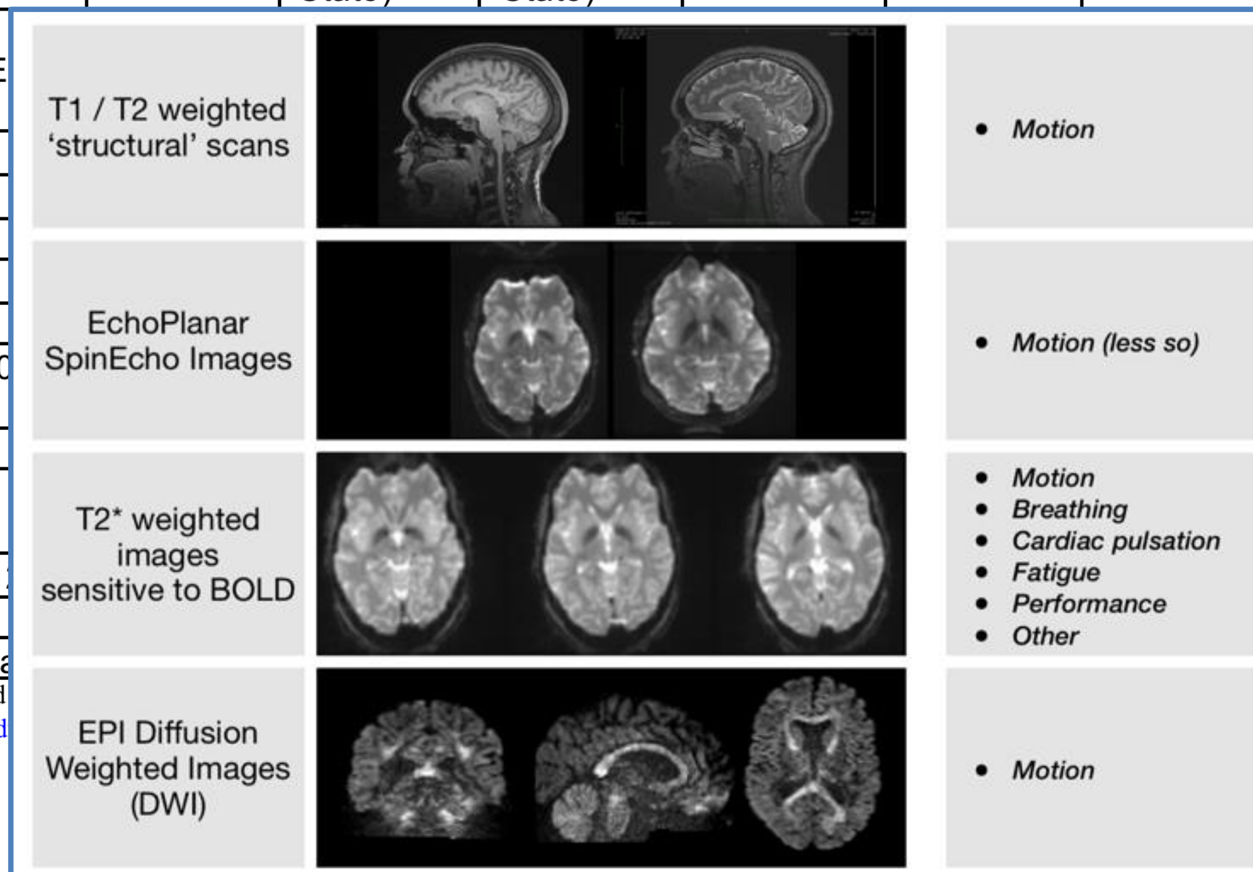
Artifacts:	Variables:
Type of Artifact:	
No Artifacts	0
CSF Pulsation Artifacts	1
Wrapping/Aliasing Artifacts	2
Shading Artifact	3
Zebra Stripes	4
Motion Artifacts	5
Magnetic Susceptibility Artifacts	6
Insufficient FOV	7
Failed Image Transfer	8
Zipping Artifact	9
Severity:	
No Artifacts	0
Minimal (non-significant)	1
Significant (but probably usable for most research questions	2
Severe (probably non-usable)	3
Location:	
No Artifacts	0
Whole Brain	1
Frontobasal	2
Frontal	3
Temporomesial	4
Occipital	5
Dienzephalon	6
Mesencephalon	7
Pons	8
Cerebellum	9
Frontal and Occipital	25

MR Sequences

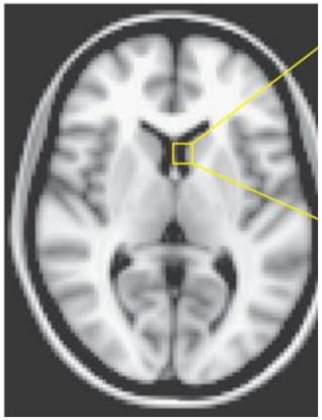


	T1-weighted	T2-weighted	EPI 1(Resting State)	EPI 2(Resting State)	Field maps	Diffusion weighted
Sequence	MP-RAGE					
TR (ms)	1900					
TE (ms)	2.22					
flip angle	9					
B value (s/mm2)	-					
Diffusion directions	-					
Resolution (mm3)	0.7 x 0 x 0.7					
Thickness	0.7					
Accelerator/Multiband factor	2/-					
Field of View	225 x					
Number of slices	176					
Imaging direction	Sagitta					

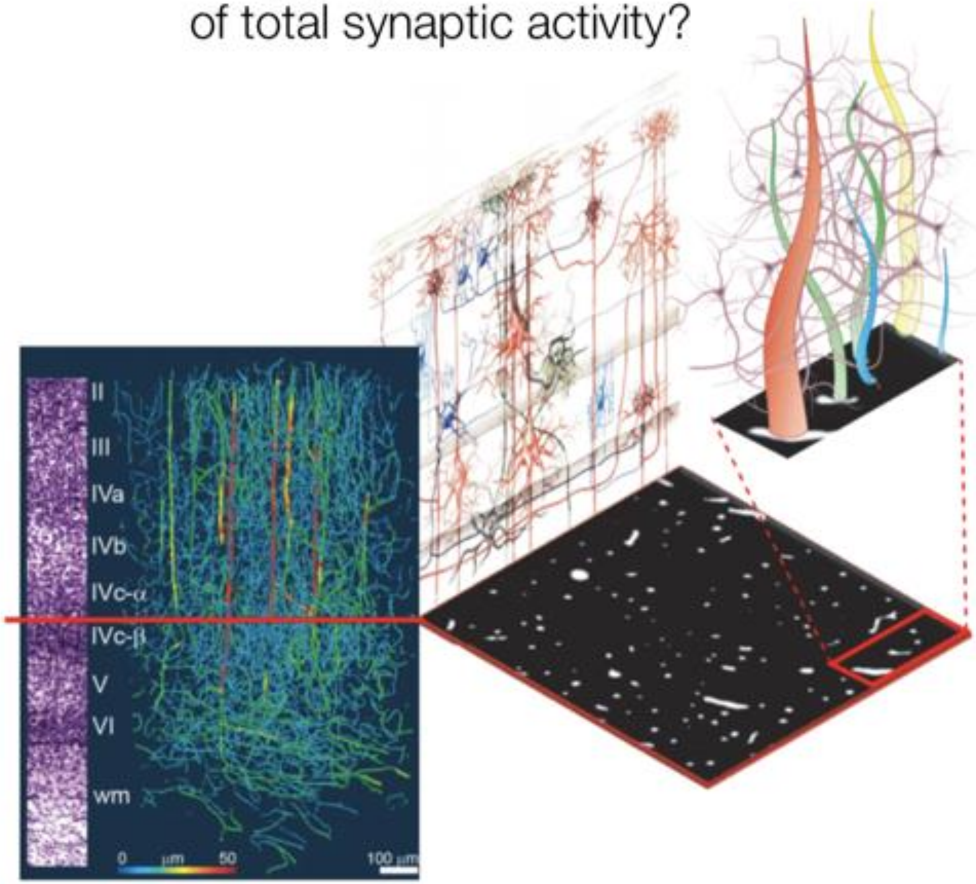
MP-RAGE = magnetization prepared-rapid
mm=milimeter; . [1]https://www.cmrr.umn.ed



Volumetr



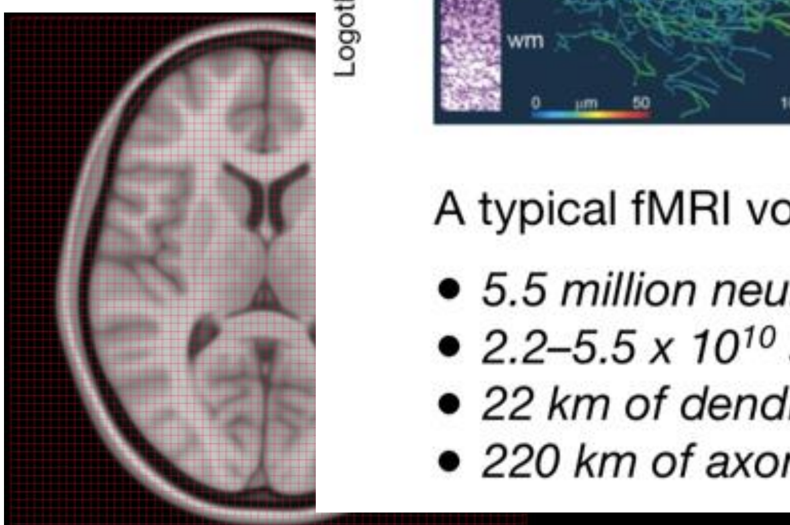
Aggregate measure of total synaptic activity?



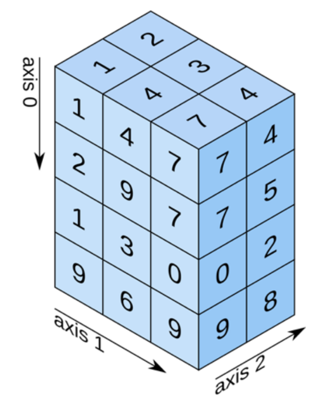
Logothetis (2008). *Nature.*

A typical fMRI voxel of 55 ml in size contains:

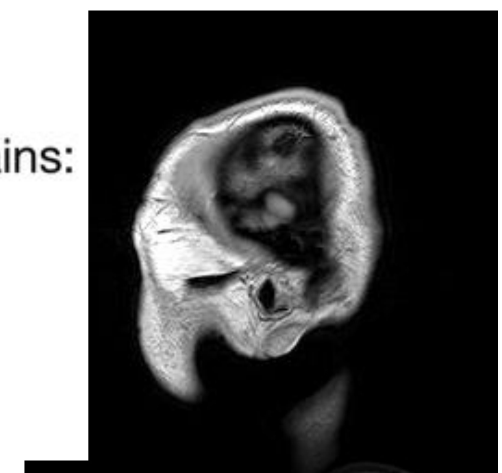
- *5.5 million neurons*
- *2.2–5.5 x 10^{10} synapses*
- *22 km of dendrites*
- *220 km of axons*



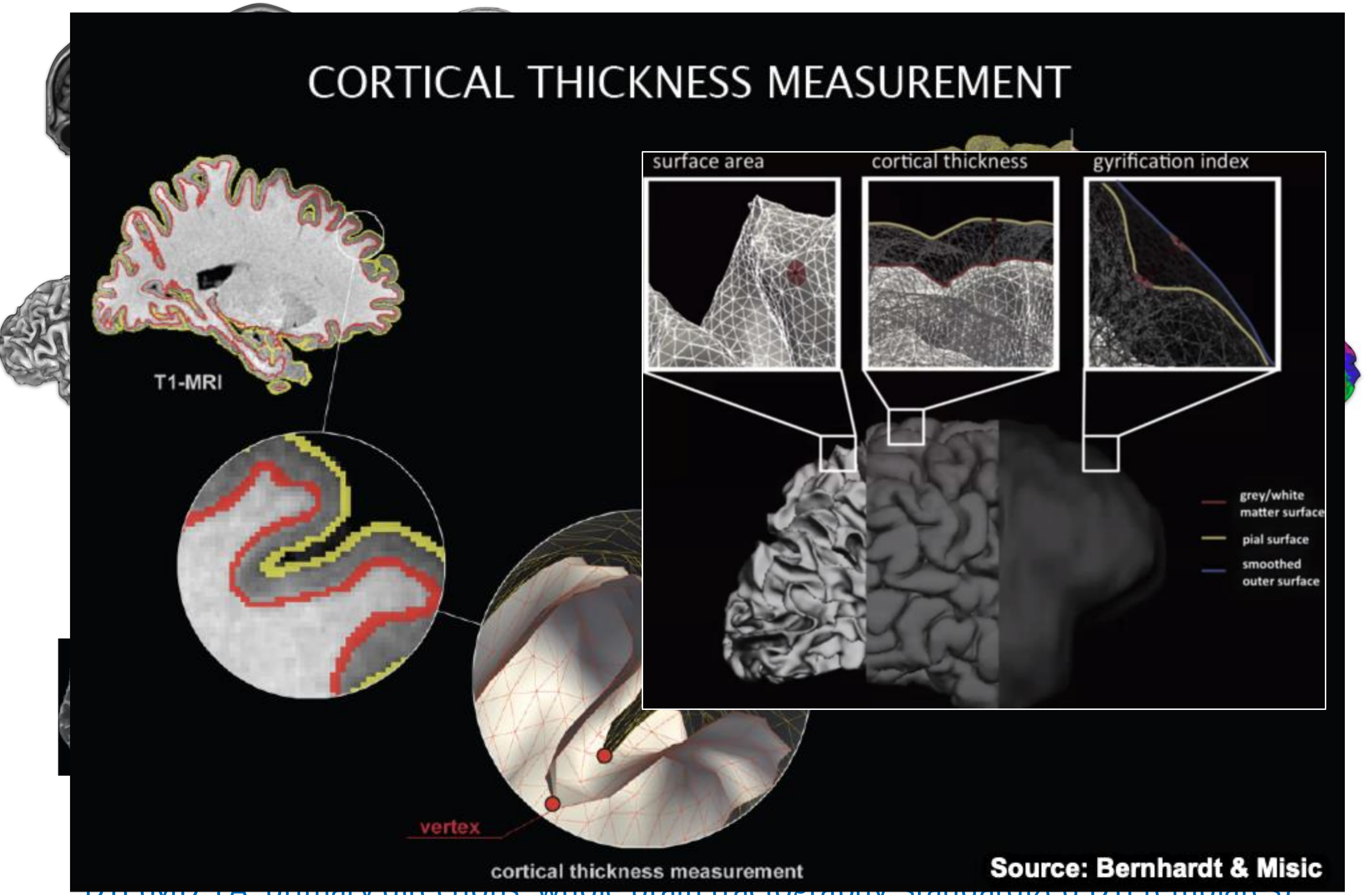
3D array



shape: (4, 3, 2)



Structural MRI



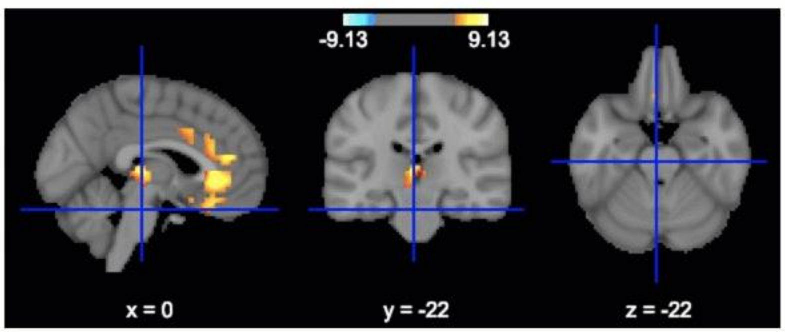
MDD meta-analysis using Neuroquery

11/2019: Encode major depression into a statistical map of the brain

```
[1]
from neuroquery import fetch_neuroquery_model, NeuroQueryModel
from nilearn.plotting import view_img

encoder = NeuroQueryModel.from_data_dir(fetch_neuroquery_model())
```

```
[8]
query = """major depression"""
result = encoder(query)
view_img(result["z_map"], threshold=5.1)
```

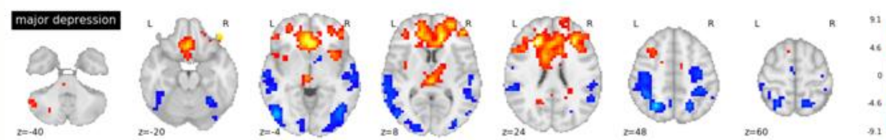


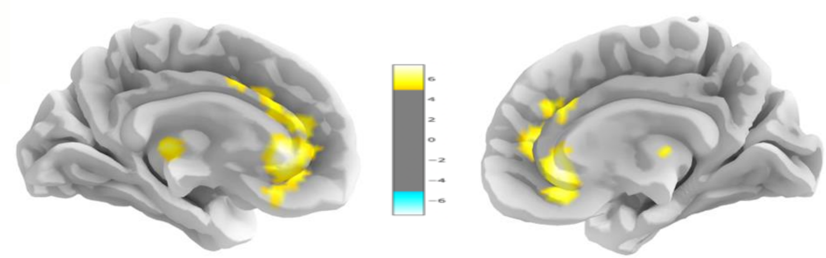

```
[16]
print("\nTerms recognized in the query:\n")
print(
    response["similar_words"]
    .query("weight_in_query != 0")
    .sort_values(by="weight_in_query", ascending=False)
    .head()
)
```

```
Terms recognized in the query:

                  similarity  weight_in_brain_map  weight_in_query  \
major depression    0.994231                  0.0              1.0

                  n_documents
major depression          896
```



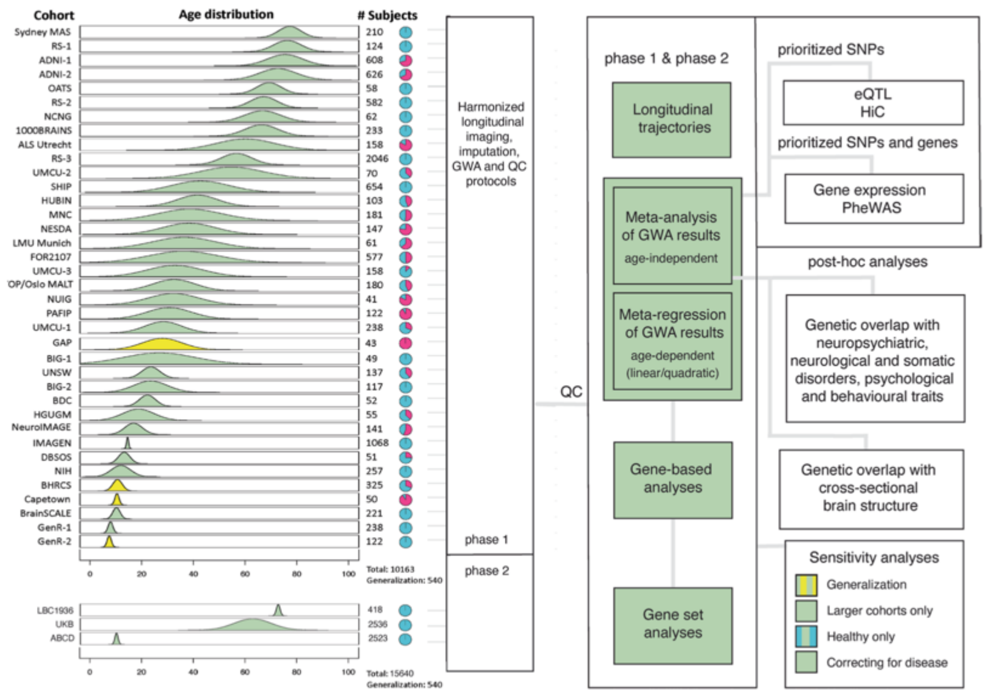


nature neuroscience
ARTICLES
https://doi.org/10.1038/s41593-022-01042-4
Check for updates

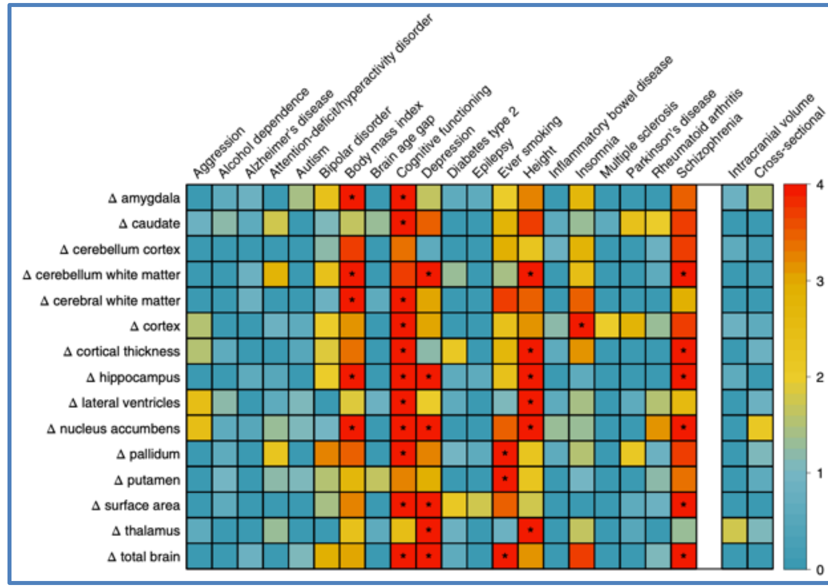
1

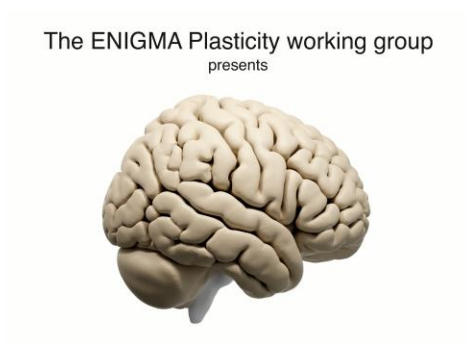
N=15640

Genetic variants associated with longitudinal changes in brain structure across the lifespan



GPR139, DACH1 und APOE

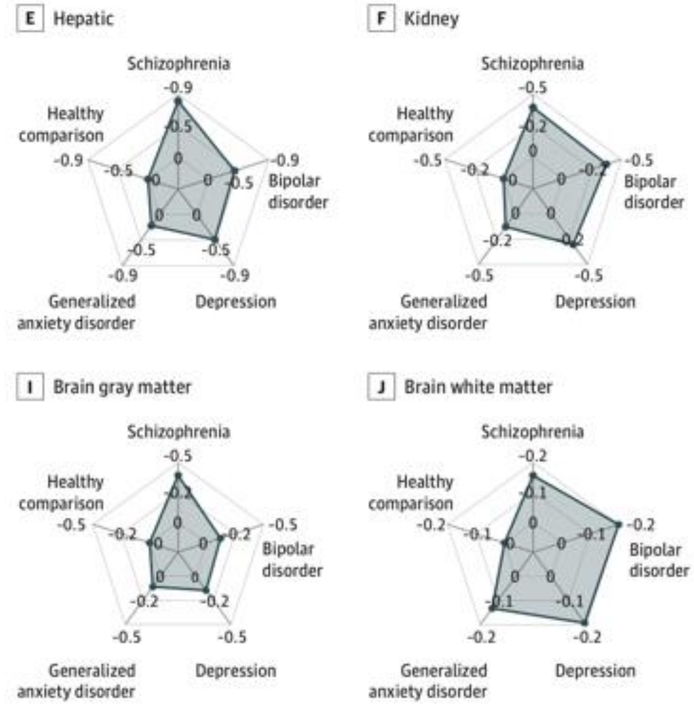




Genetic overlap
global genetic overlap with depression, schizophrenia, cognitive functioning, #insomnia, height, BMI, and smoking

Brouwer et al., Nature Neuroscience 2022

Brain Age gap across organs

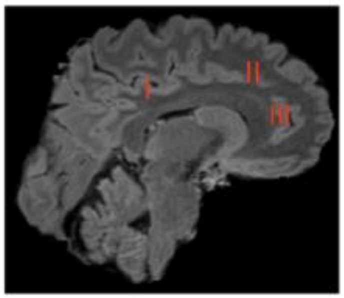


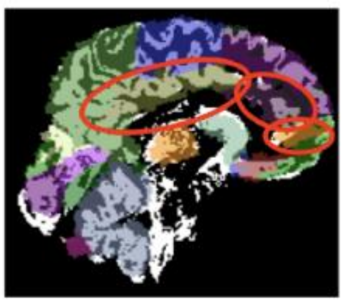
Tian et al., Nature Medicine 2023
Tian et al., JAMA Psychiatry 2023

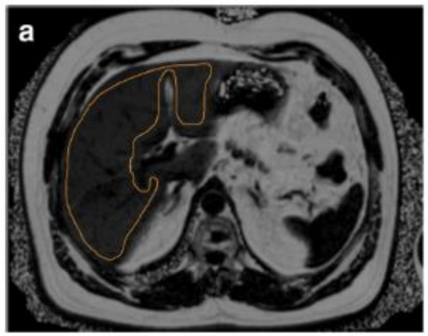
Hepatic fat is superior to BMI, visceral and pancreatic fat as a potential risk biomarker for neurodegenerative disease

European Radiology 2019

Ebba Beller[1,2] · Roberto Lorbeer[2] · Daniel Keeser[2] · Franziska Schoeppe[2] · Sabine Sellner[2] · Holger Hetterich[2] · Fabian Bamberg[3,4] · Christopher L. Schlett[3,4] · Annette Peters[5] · Birgit Ertl-Wagner[2,6] · Sophia Stoecklein[2]







MRI-based Hepatic fat

R=-0.34, p<0.01

- n=361
(152 women, 199 men)

- ICV-corrected GM
brain volume

Corrected for:

- age
- sex
- hypertension
- smoking
- BMI
- LDL
- total cholesterol
- alcohol

1

Reproducible brain-wide association studies require thousands of individuals

https://doi.org/10.1038/s41586-022-04492-9

Received: 19 May 2021

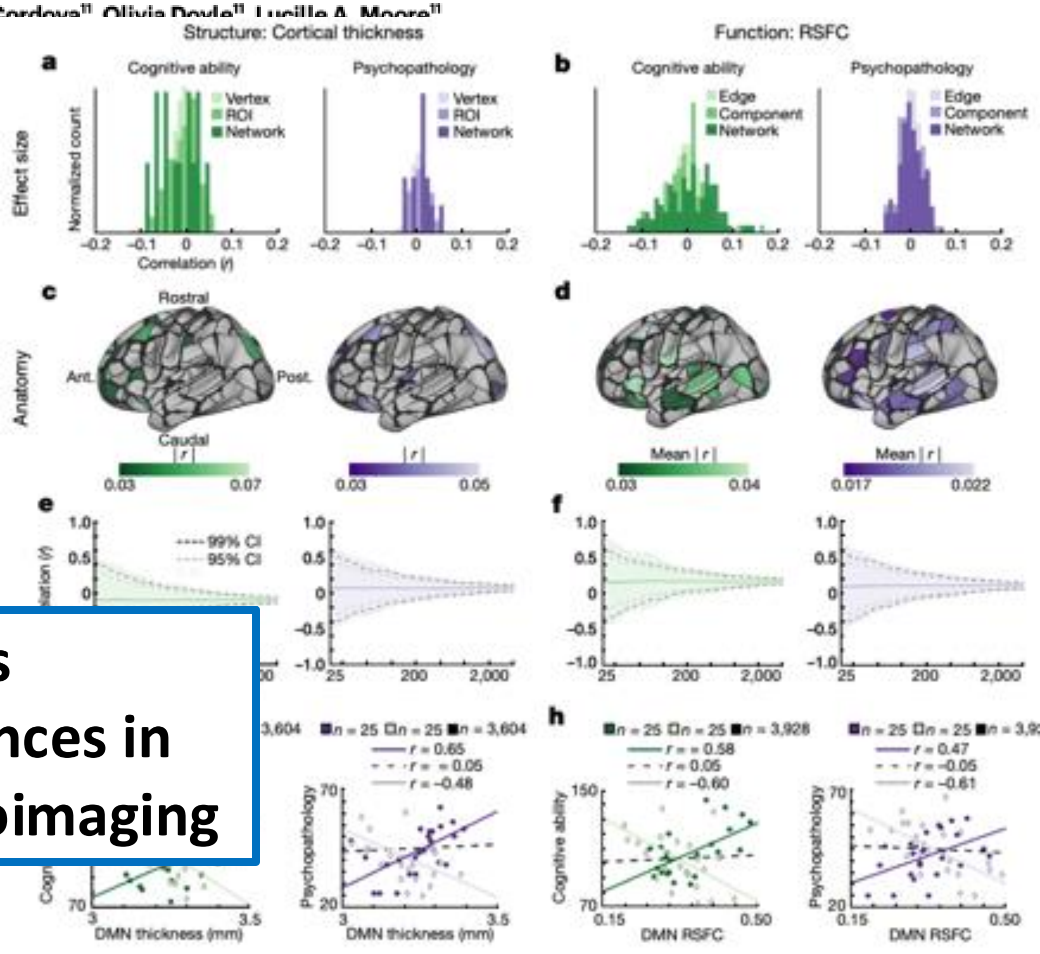
Accepted: 31 January 2022

Published online: 16 March 2022

Open access

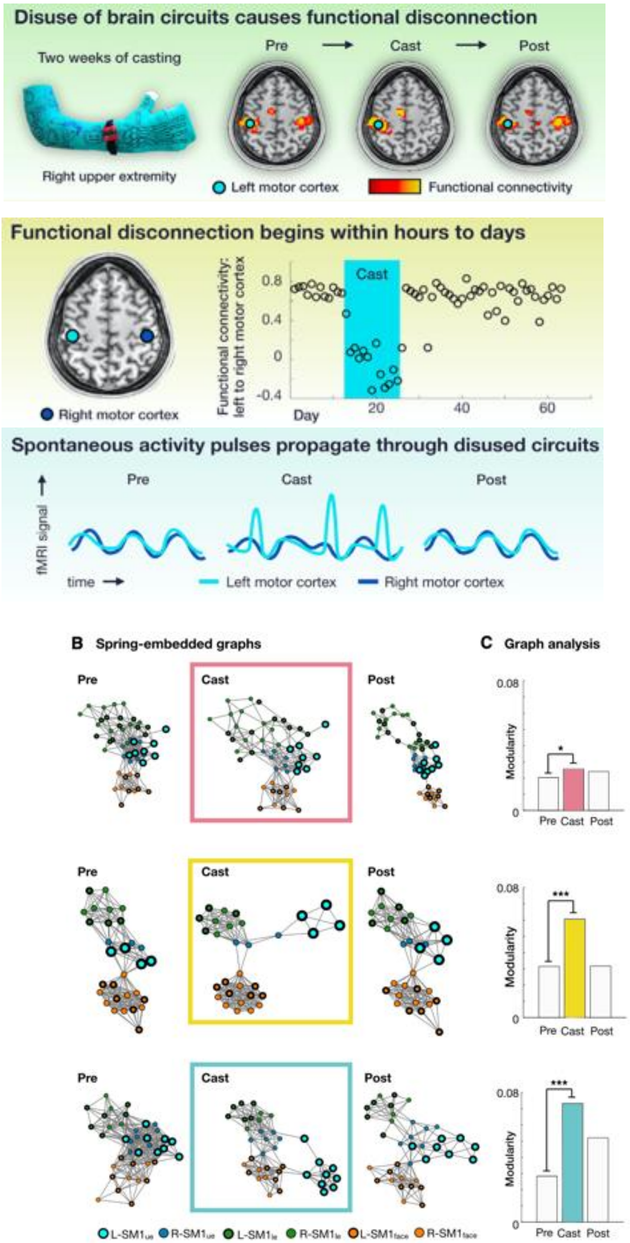
Check for updates

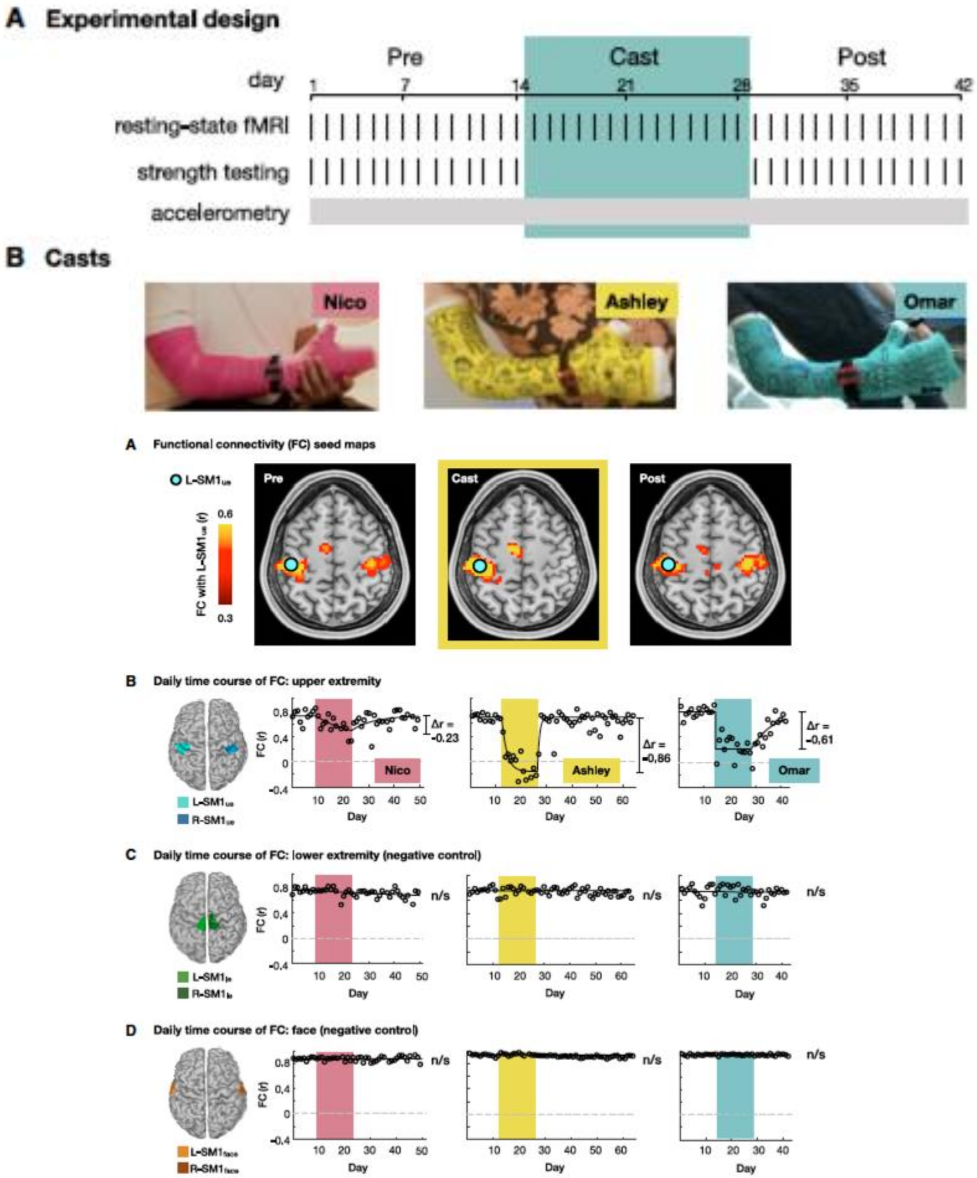
Scott Marek[1,30], Brenden Tervo-Clemmens[2,3,30], Finnegan J. Calabro[4,5], David F. Montez[6], Benjamin P. Kay[6], Alexander S. Hatoum[1], Meghan Rose Donohue[1], William Foran[4], Ryland L. Miller[1,6], Timothy J. Hendrickson[7], Stephen M. Malone[8], Sridhar Kandala[1], Eric Feczko[9,10], Oscar Miranda-Dominguez[9,10], Alice M. Graham[11], Eric A. Earl[9,11], Anders J. Perrone[9,11], Michaela Cordova[11], Olivia Doyle[11], Lucille A. Moore[11], Gregory M. Conan[9,11], Johnny Ur
James C. Wilgenbusch[9,12], Thom
Dillan J. Newbold[6], Annie Zheng
Roselyne J. Chauvin[6], Timothy C
Hugh Garavan[22], Wesley K. Tho
Deanna M. Barch[1,21], Beatriz Lun



cross-sectional correlations between individual differences in functional/structural neuroimaging

Well-designed studies do not need a large N





Newbold et al., Neuron 2020

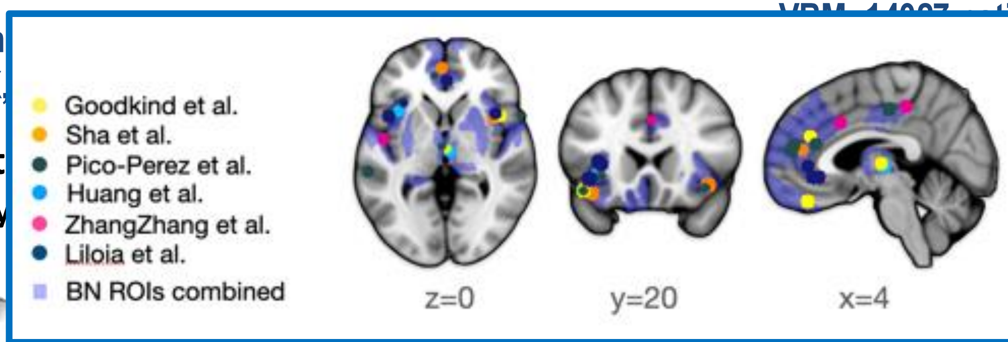
Transdiagnostic network changes in psychiatric diseases

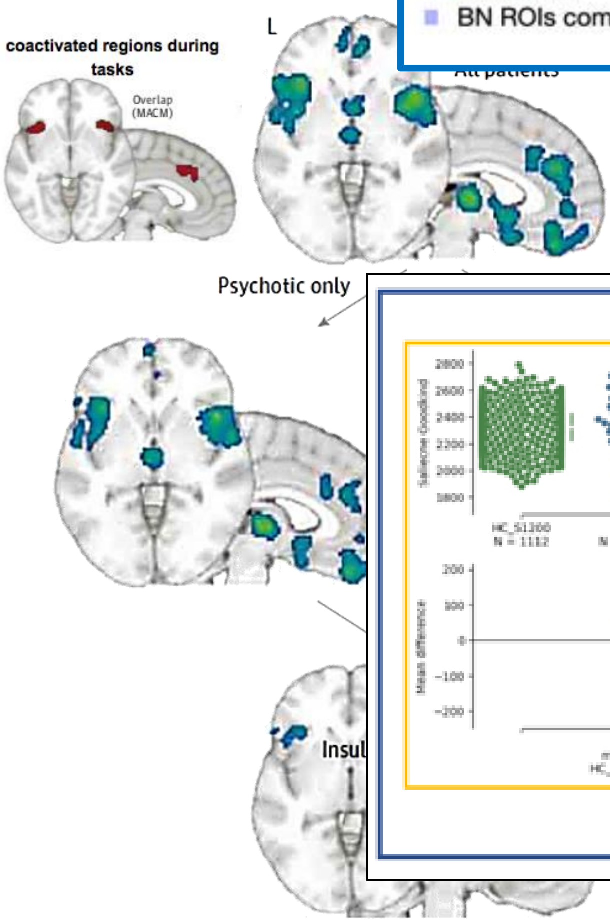
- 7381 patients, 8511 m
- SCZ, BPD, MDD, ANX,

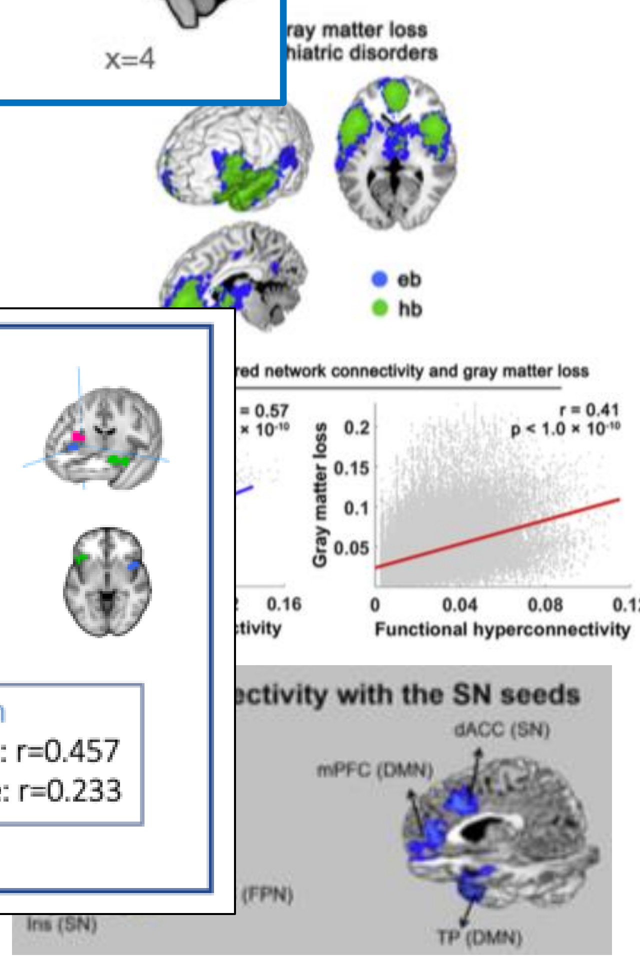
Overlap of struct

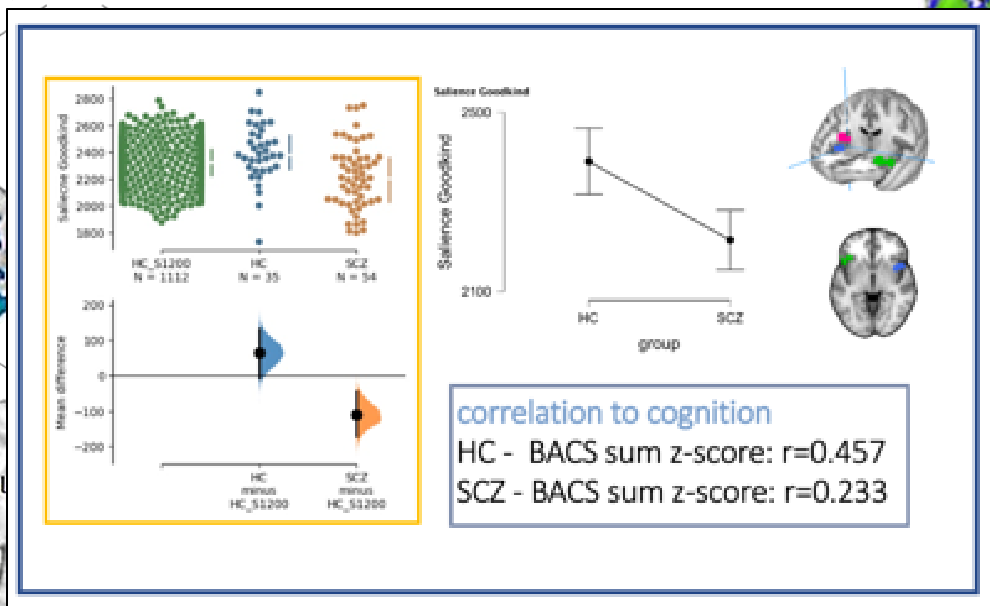
(based on meta-analy

...nts, 14504 HC
...nalysis of 363 VBM studies)
...MRI: 8298 patients, 8165 HC
...nalysis of 242 rsfcMRI studies)
...orders









Goodkind et al., *JAMA Psychiatry* 2015

Sha et al., *Biological Psychiatry* 2018

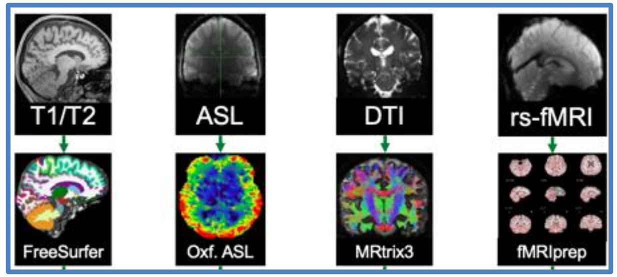
Neuroimaging modalities

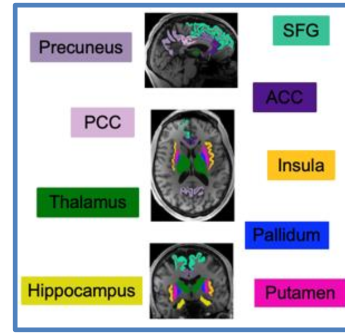
Sample characteristics

Data set	N	Age range	Sex
HCP-Ageing	725	36 – 100 years	406 ♀, 319 ♂
MPI Leipzig:	227	20 – 85 years	82 ♀, 145 ♂

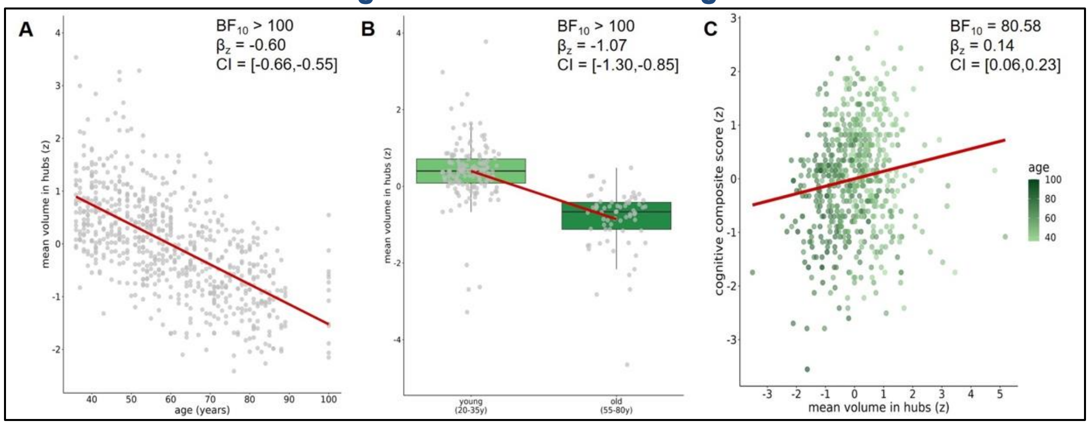
HUMAN Connectome PROJECT

N=952

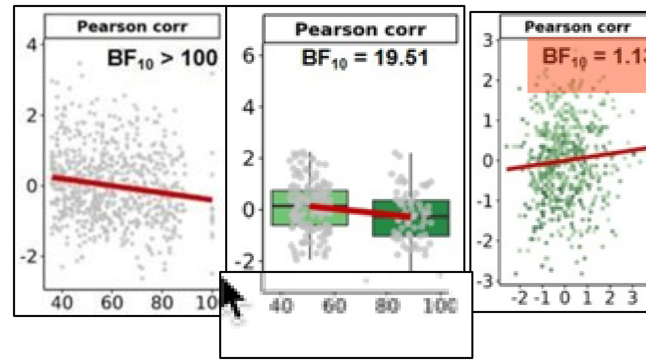




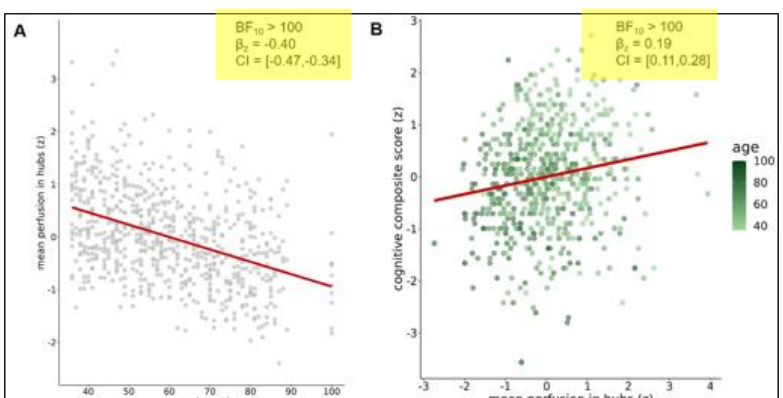
Structural MRI: Age - Brain Volumes - Cognition



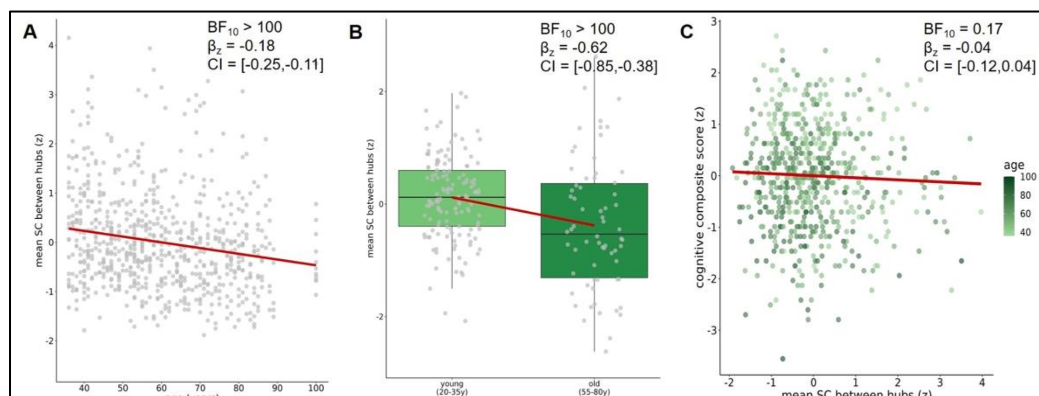
rs-fMRI: Age – Functional Connectivity – Cognition



ASL: Age – Brain Perfusion – Cognition



DTI: Age – Structural Connectivity – Cognition

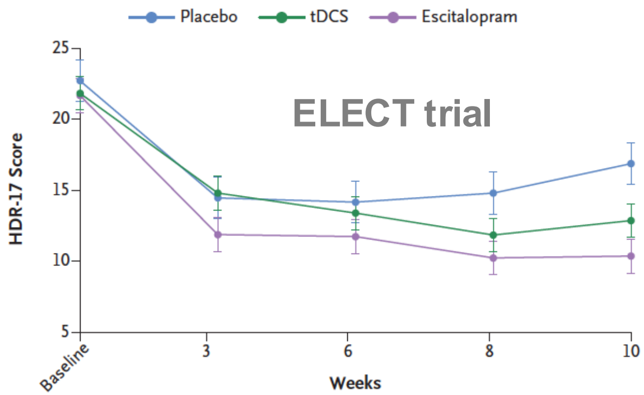


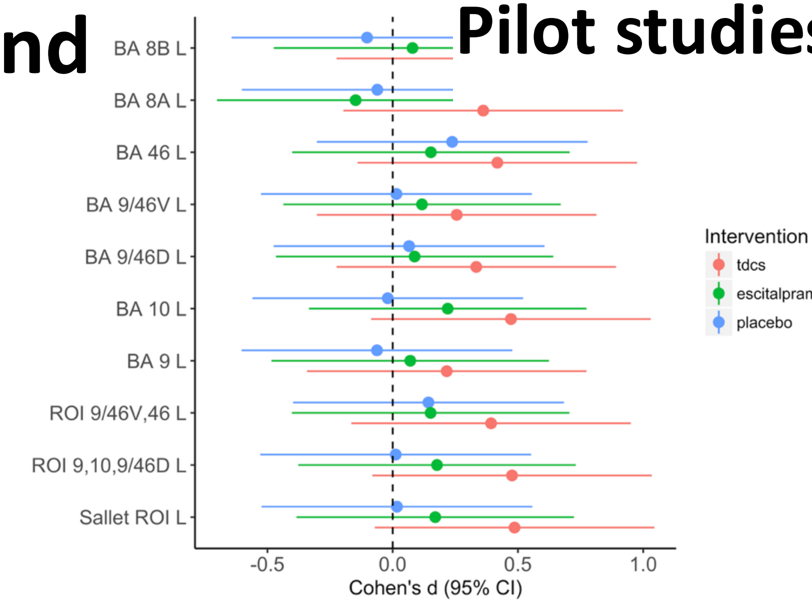
https://www.biorxiv.org/content/10.1101/2024.03.18.585458v1

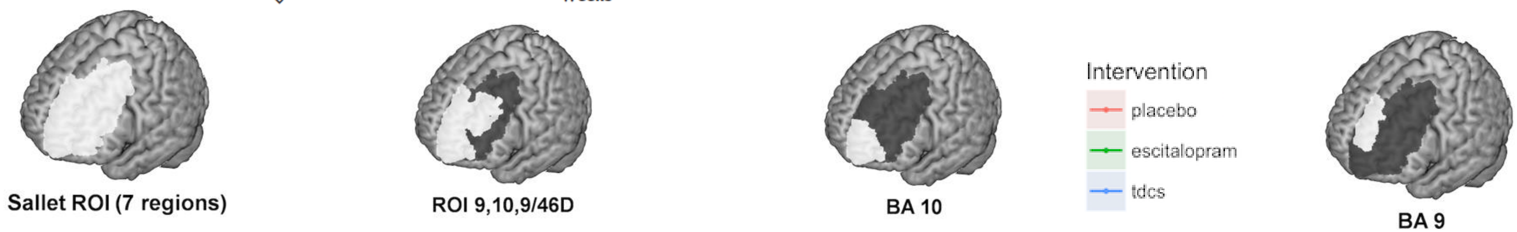
Roell et al., submitted

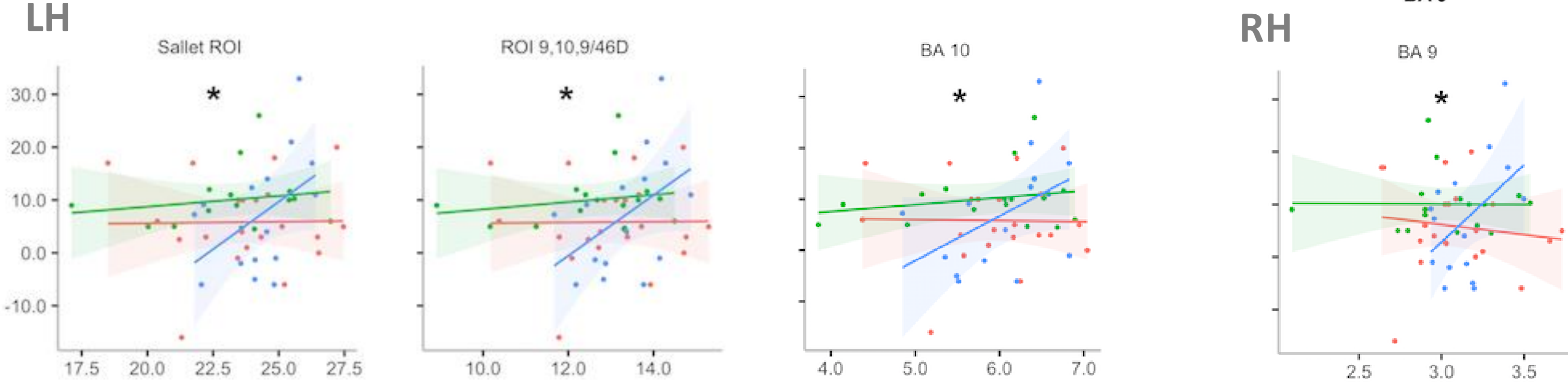
Associsation of GM volume and antidepressive response

Pilot studies







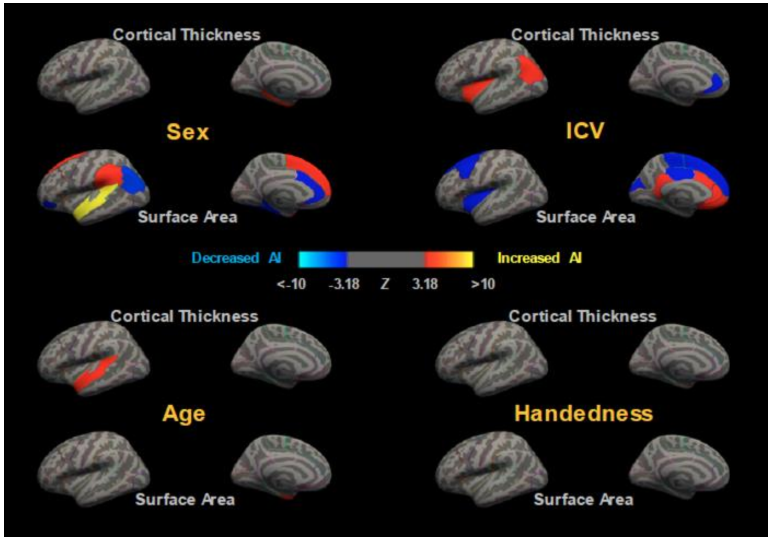


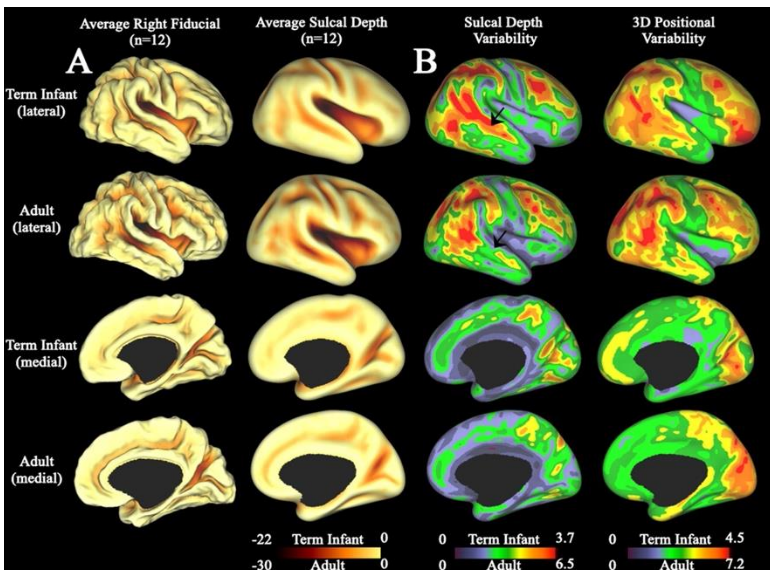
Brunoni et al., New England Journal of Medicine 2017

Bulubas et al., Brain Stimulation *2019*

Anatomical variability

+ 17141 subjects
99 datasets worldwide





Kong et al., *PNAS* 2018
J. Hill, *Journal of Neuroscience*, 2010

Seibt, *Brain Stimulation*, 2015

Contents lists available at ScienceDirect

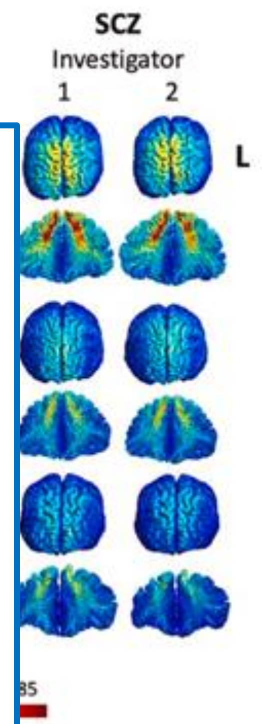
NeuroImage: Clinical

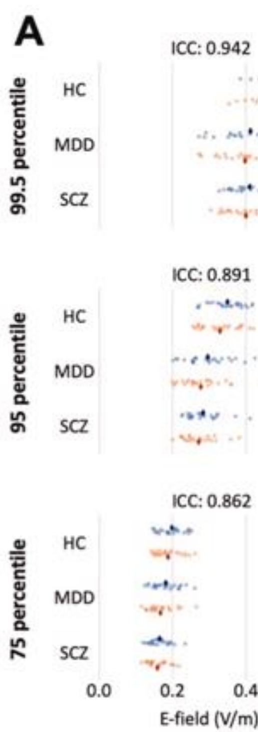
journal homepage: www.elsevier.com/locate/ynicl

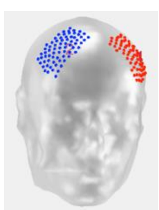
Differences in electric field strength between clinical and non-clinical populations induced by prefrontal tDCS: A cros[...] MRI-based modeling study

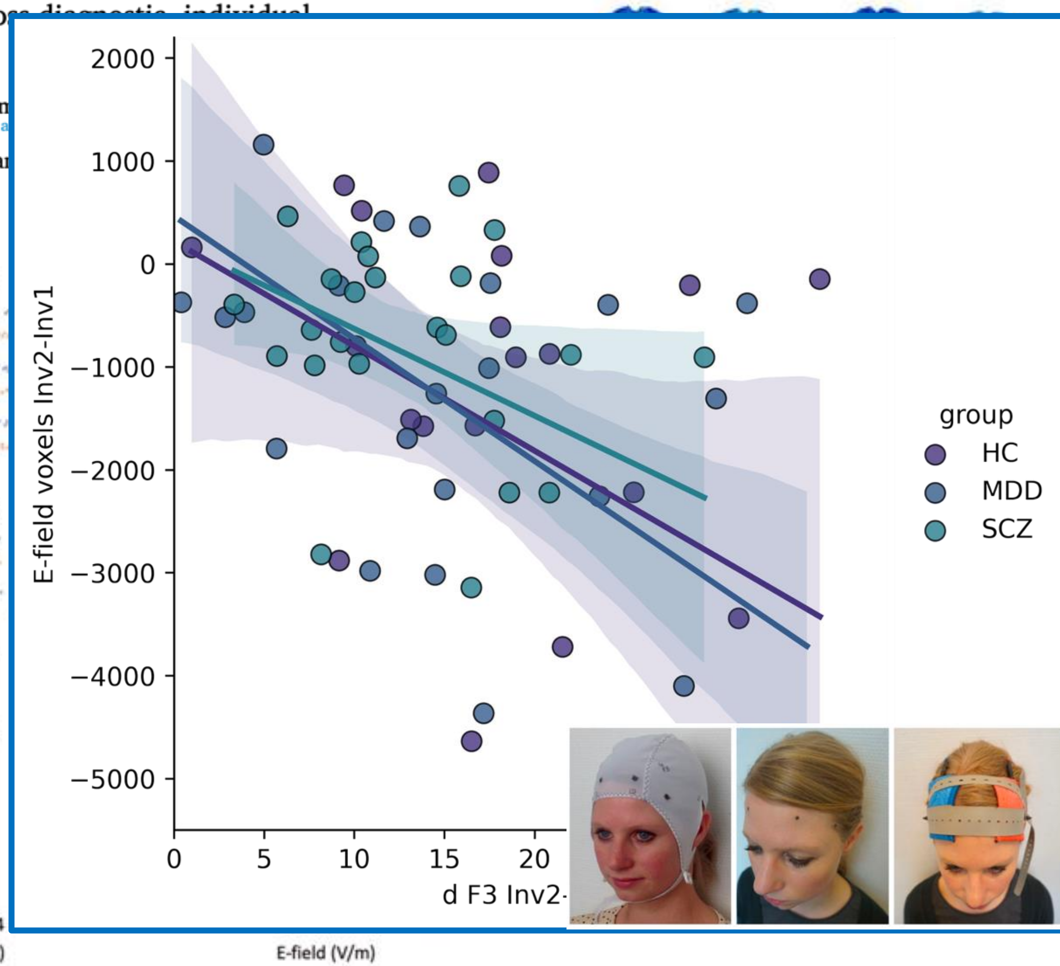
Yuki Mizutani-Tiebel[a,b,1,*], Shun Takahashi[a,c,d,e,f,1], Temn[...]
Lucia Bulubas[a,h], Irina Papazova[a,i], Esther Dechantsreiter[...]
Boris Papazov[b,g], Axel Thielscher[j,k], Frank Padberg[a,1], Dar[...]

HC, n=25
MDD, n=25
SCZ, n=24





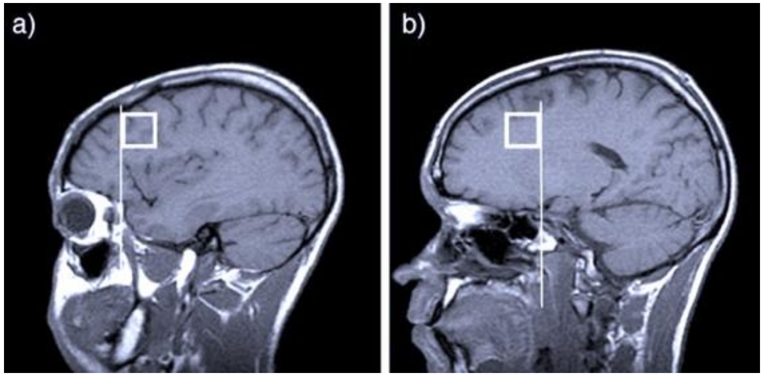


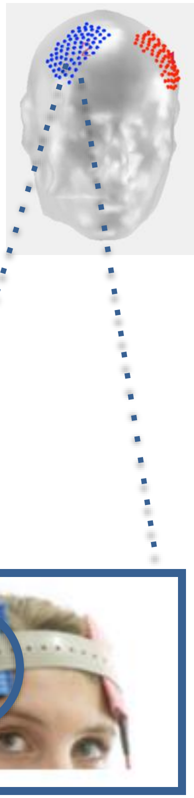


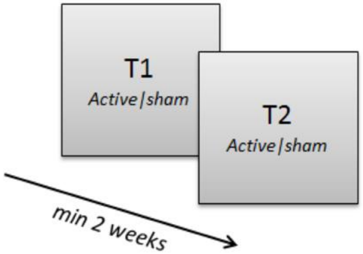
Mizutani-Tiebel, Takahashi et al., *NeuroImage Clinical* 2022

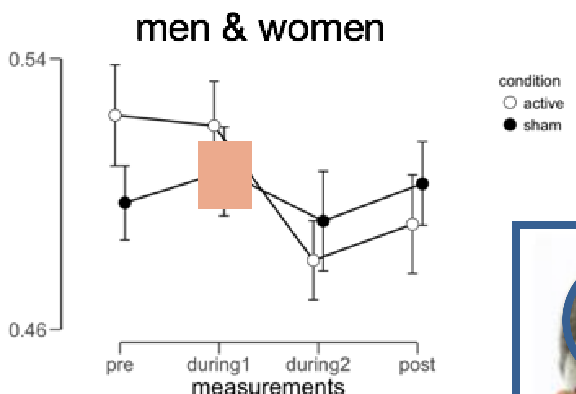
Magnetic Resonance Spectroscopy – MRSDC0

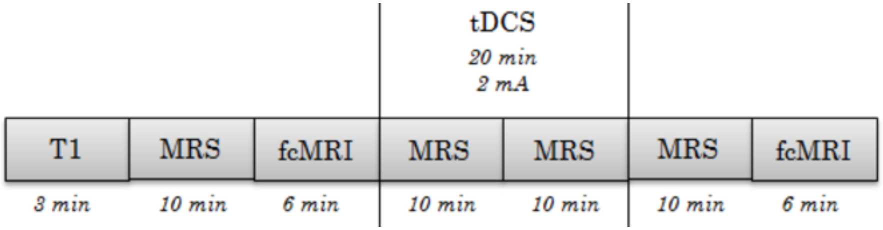
- cross-over design, healthy subjects, gender-mixed sample, n=19, MRSDC0
- translational: study on major depressive patients and schizophrenic patients (MRSDC1)

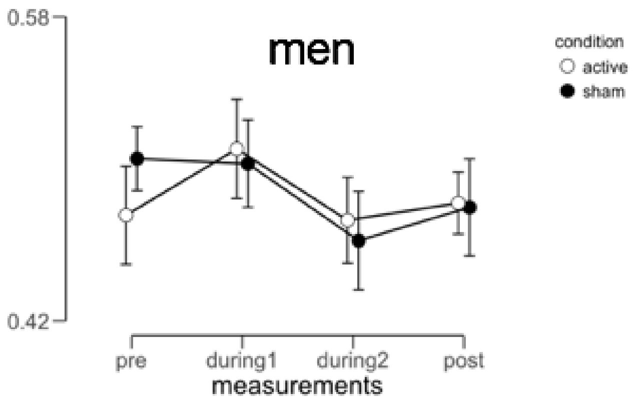


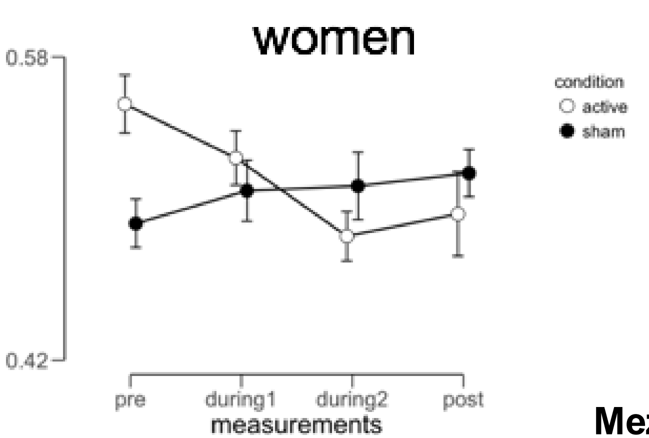


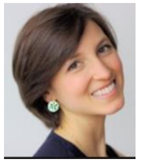








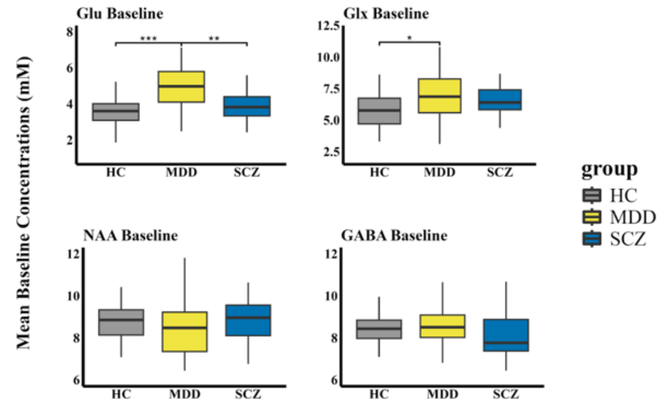


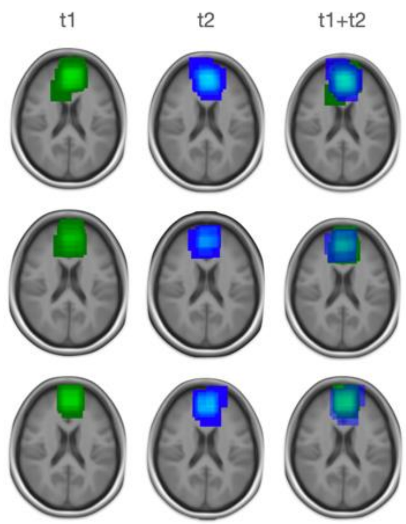


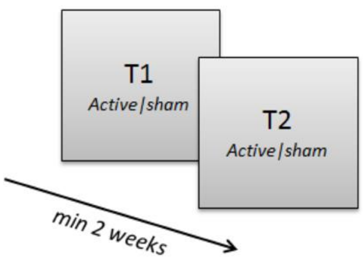
Mezger et al., EAPCN 2020

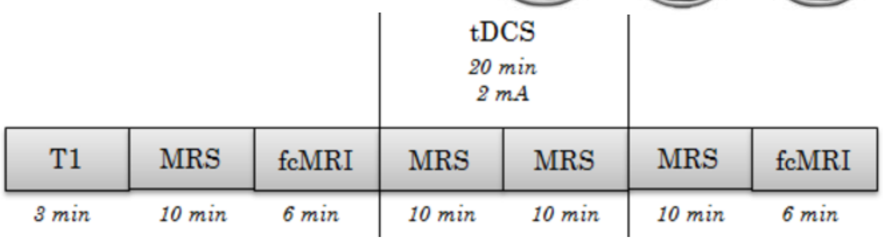
Magnetic Resonance Spectroscopy – MRSDC1

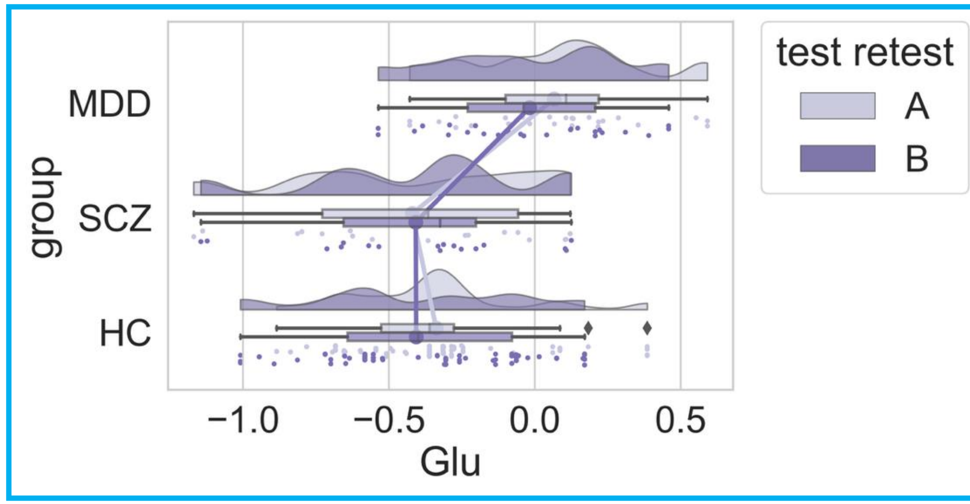
HC, N=38
MDD, N=24 (un-medicated)
SCZ, N=17
Total N=79

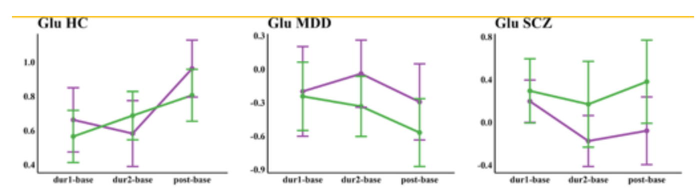


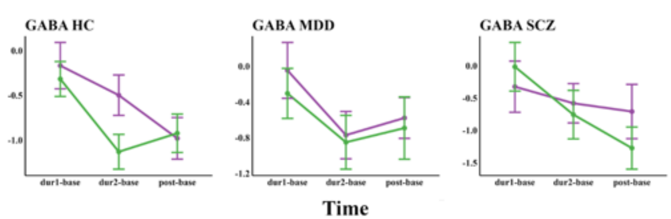






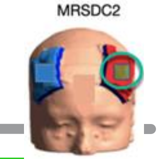




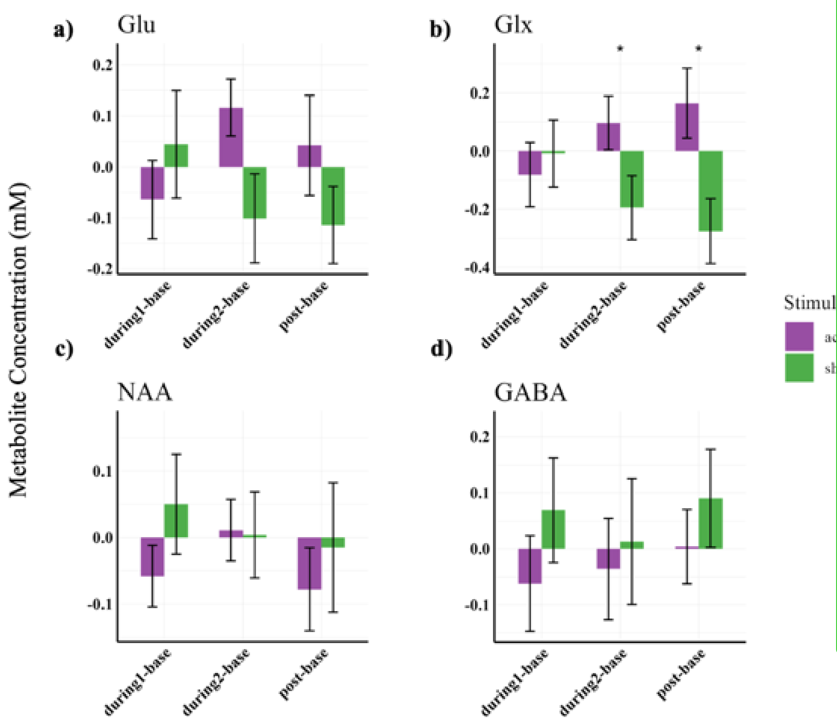


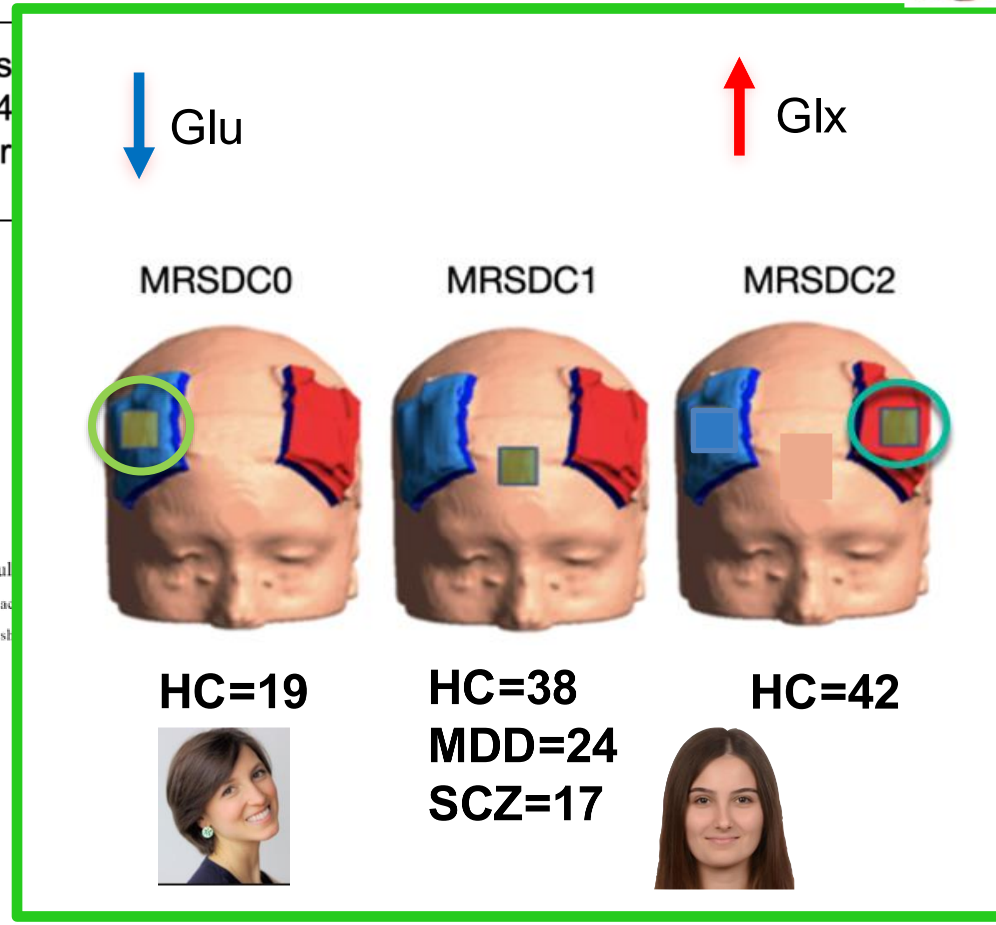
Vural et al. in prep.

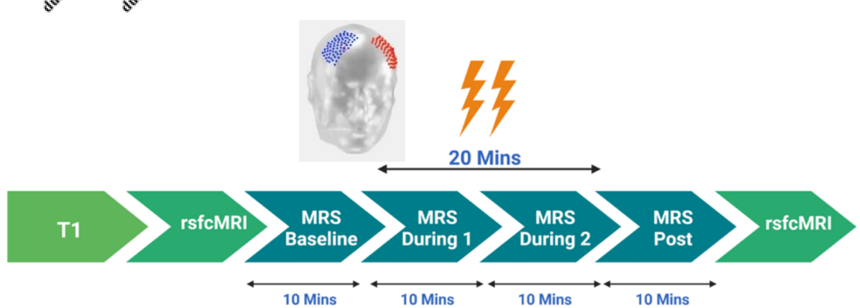
Magnetic Resonance Spectroscopy – MRSDC2



Design: Double Blind Placebo-Controlled, cross
Sample: 41 healthy participants (21 males, ± 24
Scanner: Siemens Prisma 3-Tesla MRI scanner
tDCS Device: NeuroConn DC-Stimulator Plus

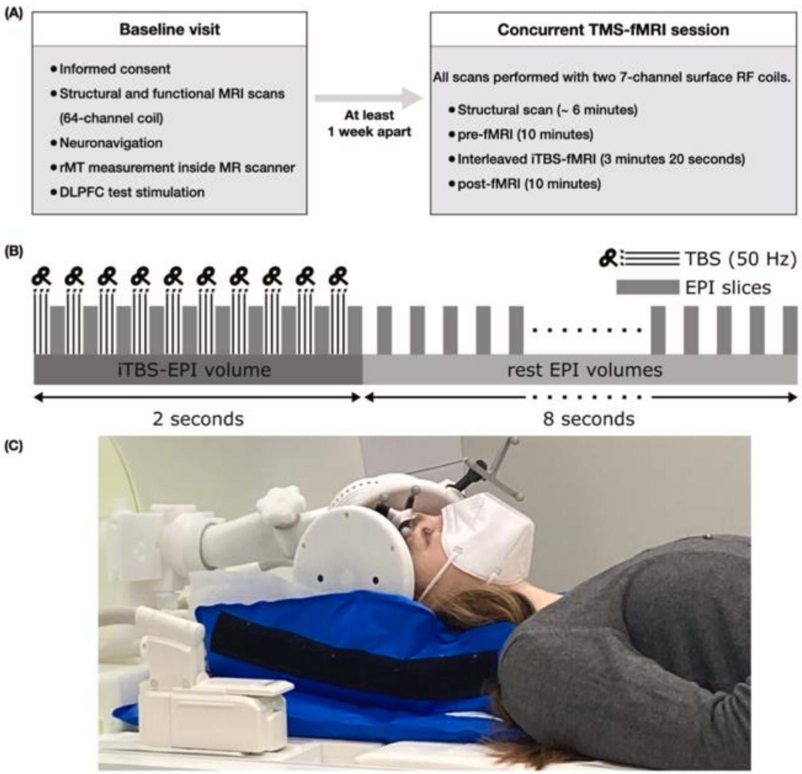


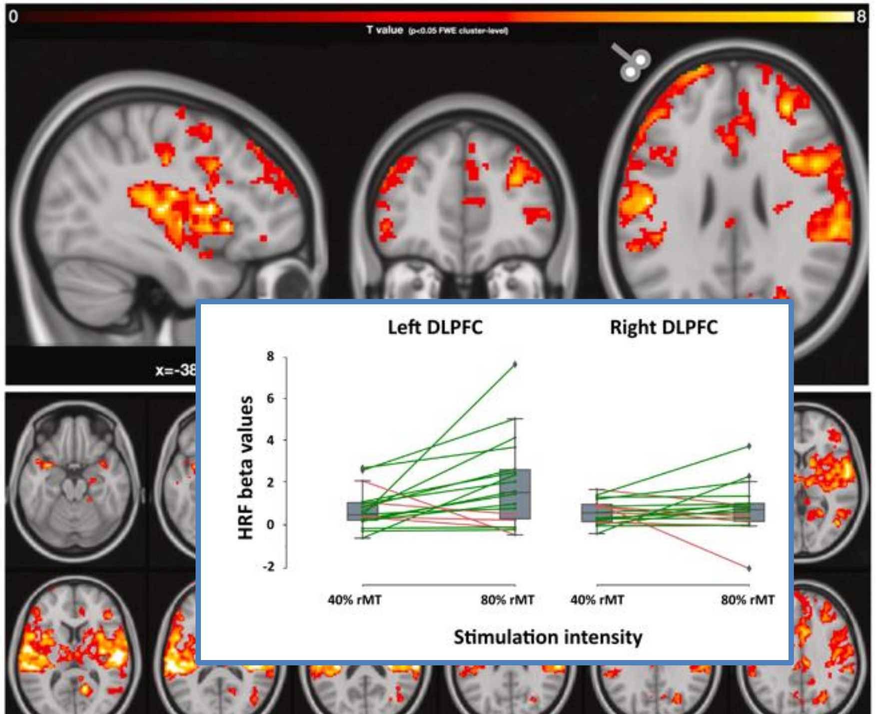


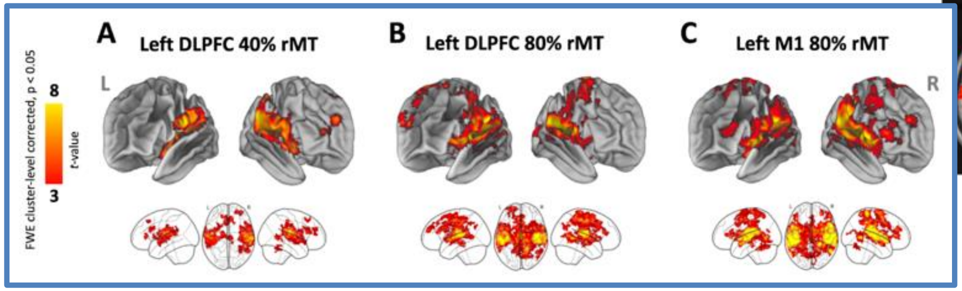


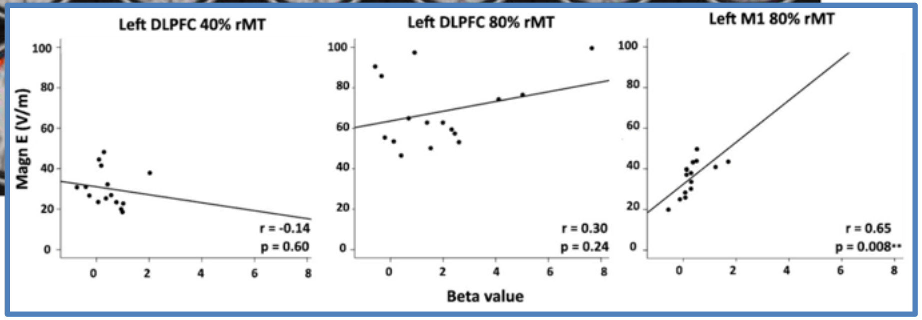
Vural et al. under review

Online TBS-fMRI







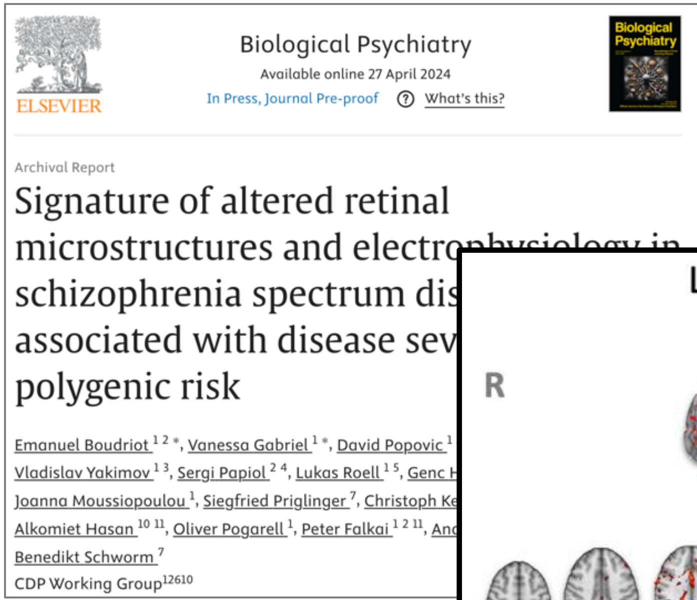


Mizutani-Tiebel et al., *Frontiers in Psychiatry* 2022

Chang et al., *NeuroImage 2024*

Chang et., *Biological Psychiatry:CNNI 2024*

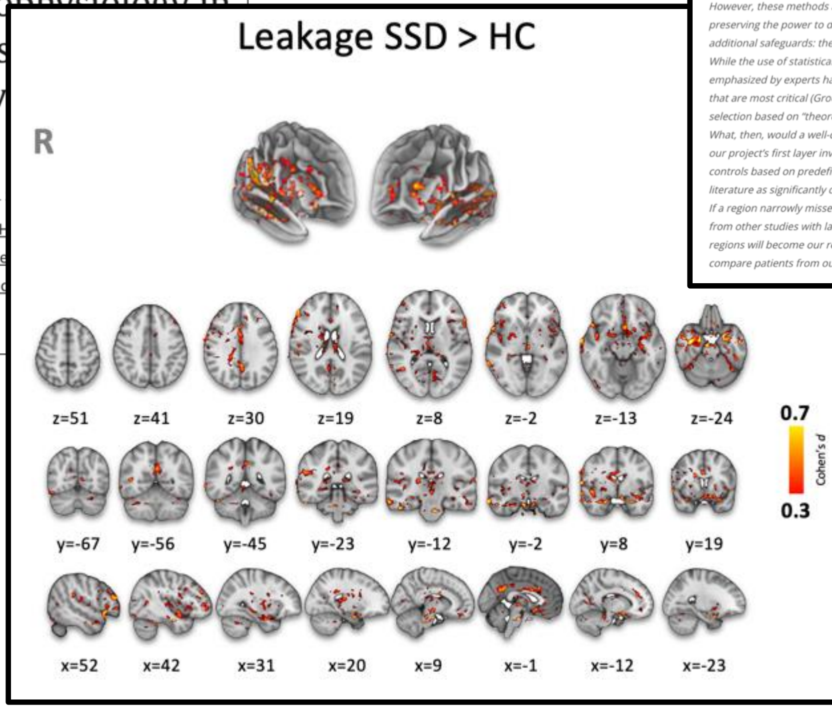
Ongoing CDP research


Biological Psychiatry
Available online 27 April 2024
In Press, Journal Pre-proof What's this?

Archival Report

Signature of altered retinal microstructures and electrophysiology in schizophrenia spectrum dis… associated with disease sev… polygenic risk

Emanuel Boudriot [1 2 *], Vanessa Gabriel [1 *], David Popovic [1], Vladislav Yakimov [1 3], Sergi Papiol [2 4], Lukas Roell [1 5], Genc H…, Joanna Moussiopoulou [1], Siegfried Priglinger [7], Christoph Ke…, Alkomiet Hasan [10 11], Oliver Pogarell [1], Peter Falkai [1 2 11], And…, Benedikt Schworm [7]
CDP Working Group[12610]



Multimodal Clustering Analysis of meta-analytically derived brain regions in Schizophrenia Spectrum Disorder

Contributors: Maxim Korman, Daniel Keeser

Date created: 2024-03-18 05:29 PM | Last Updated: 2024-06-11 02:51 AM

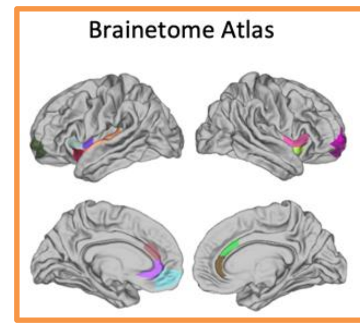
Category: Analysis

Description: *Schizophrenia Spectrum Disorders (SSD) represent a broad spectrum of psychotic disorders. Their prevalence and severity highlight the urgent need for a deeper understanding of these heterogeneous diseases, which is crucial for developing tailored treatment strategies.*

A key determinant of progress in any scientific field is the discovery of associations that, over time, demonstrate replicability. Given our inability to completely eliminate the chance of finding false positives (i.e., to reject the null hypothesis definitively), an error threshold of 5% (p-value of 0.05) has been widely accepted. As we enter the era of big data, and hence an era of being able to test for an almost unlimited number of hypotheses, established thresholding becomes problematic, leading to a significant number of false positives (up to 1 in every 20 tests). To address this, multiple testing correction methods such as the Bonferroni correction and the False Discovery Rate (FDR) have been used. However, these methods are never a perfect solution, but rather represent trade-offs between minimizing the risk of false positives while preserving the power to detect true associations. To further increase the likelihood that the associations we detect are valid, we implement two additional safeguards: the pre-selection of our hypotheses and the pre-registration of our analyses.

While the use of statistical corrections for multiple testing has become standard practice, other methodological aspects that are frequently emphasized by experts have received less attention. Groenwold et al. suggest reducing the number of hypotheses tested by prioritizing those that are most critical (Groenwold et al., 2021). Similarly, a recent article on replicability in brain imaging supports this by recommending a pre-selection based on "theoretical considerations" (Kelly et al., 2022).

What, then, would a well-considered hypothesis in the area of brain imaging be based upon? A variety of methods are conceivable. To this end, our project's first layer involves finding all meta-analyses that address gray matter volume differences between SSD patients and healthy controls based on predefined criteria (see Analysis Plan for the specific criteria). We will then identify brain regions that have been reported in literature as significantly different more than once. We commit to including regions reported in at least half of the meta-analyses in our analysis. If a region narrowly misses this threshold in meta-analyses but is supported by strong theoretical arguments—evidenced by consistent results from other studies with large sample sizes and rigorous methodological designs—we will consider including it in our study. Collectively, these regions will become our regions of interest (ROIs), which we will examine in our cohort for patients vs. healthy controls (HC). Additionally, we will compare patients from our cohort with an age and sex matched group of HC from the Human Connectome Project (HCP).



Investigation of choroid plexus variability in schizophrenia-spectrum disorders – insights from a multimodal study

Vladislav Yakimov, Joanna Moussiopoulou, Lukas Roell, Matin Mortazavi, Iris Jäger, Emanuel Boudriot, Genc Hasanaj, Mattia Campana, Lenka Krčmář, Marcel S. Kallweit, Sean Halstead, Nicola Warren, Dan Siskind, Sergi Papiol, Isabel Maurus, Alkomiet Hasan, Peter Falkai, Andrea Schmitt, Florian Raabe, Daniel Keeser, Elias Wagner

Boudriot et al., *Biological Psychiatry 2024*
Moussiopoulou et al, *under review*
Korman et al., *in preparation*
Yakimov et al, *under review*

PNAS

Lack of group-to-individual generalizability is a threat to human subjects research

Aaron J. Fisher[a,1], John D. Medaglia[b,c], and Bertus F. Jeronimus[d]

[a]Department of Psychology, University of California, Berkeley, CA 94720; [b]Department of Psychology, Drexel University, Philadelphia, PA 19104; [c]Department of Neurology, University of Pennsylvania, Philadelphia, PA 19104; and [d]Department of Developmental Psychology, Faculty of Behavioural and Social Sciences, Groningen University, 9712 TS Groningen, The Netherlands

Feature Review

Building a Science of Individual Differences from fMRI

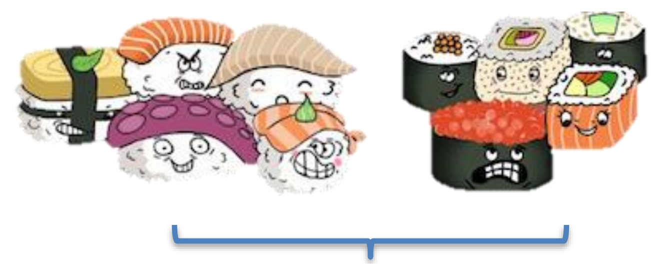
CellPress

Julien Dubois[1,*] and Ralph Adolphs[1]

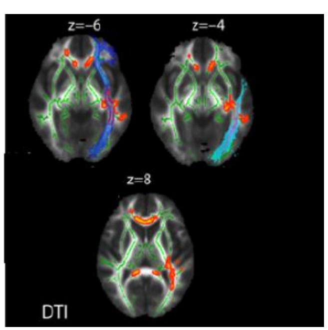
Trends in Cognitive Sciences

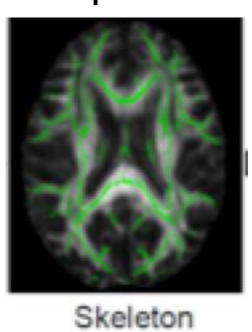
Group average of all sushis

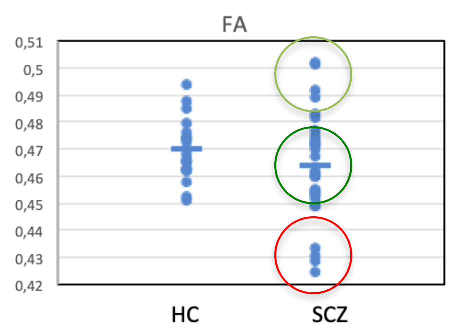
Patients healthy subjects



n=36 schizophrenia n=32







Even within group no two subjects are alike

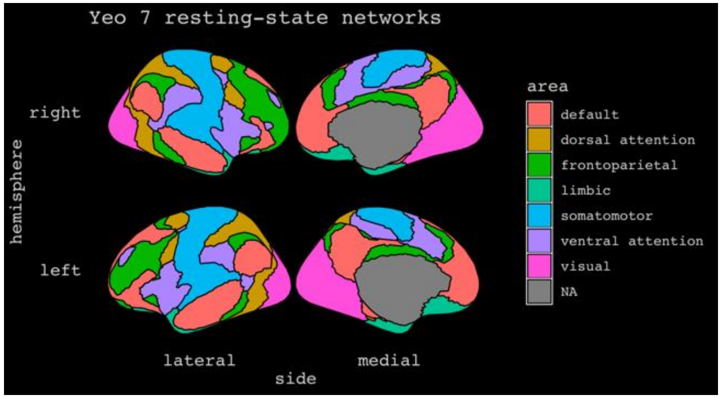
Sushis adapted from *Nora Maria Raschle*

Takahashi et al., in preparation

challenges

(Individual) Brain parcellation

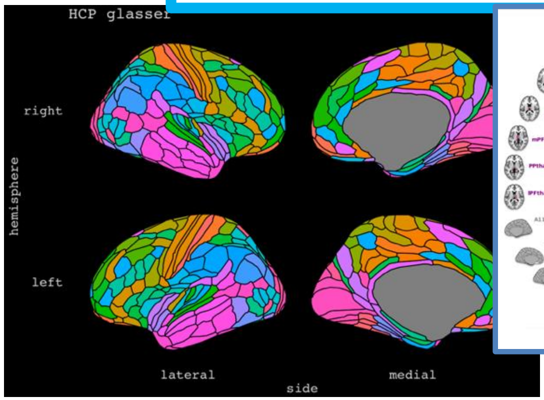
„Classical“ RSN atlas



rsfcMRI

Yeo et al., J Neurophysiol 2011

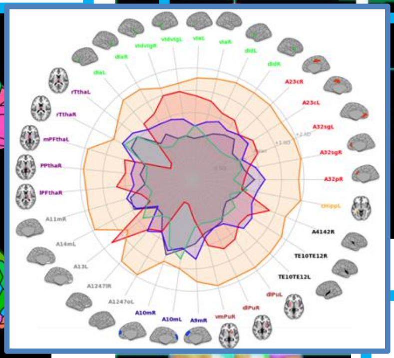
Glasser -Multimodal atlas1

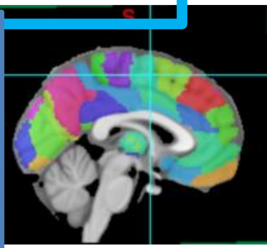


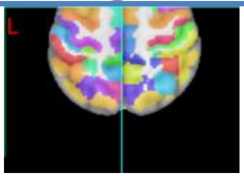
rsfcMRI
task-fMRI
Myelin maps (T1/T2)

Glasser et al., Nature 2015

Brainetome –
Multimodal atlas2



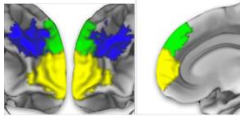


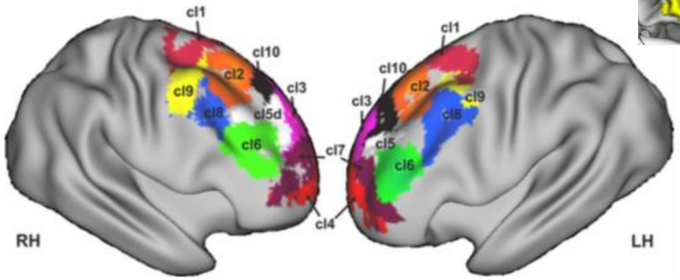


rsfcMRI
task-fMRI
DTI

Fan et al., Cerebral Cortex 2016

Dorsal frontal Cortex Atlas in Humans and Macaques



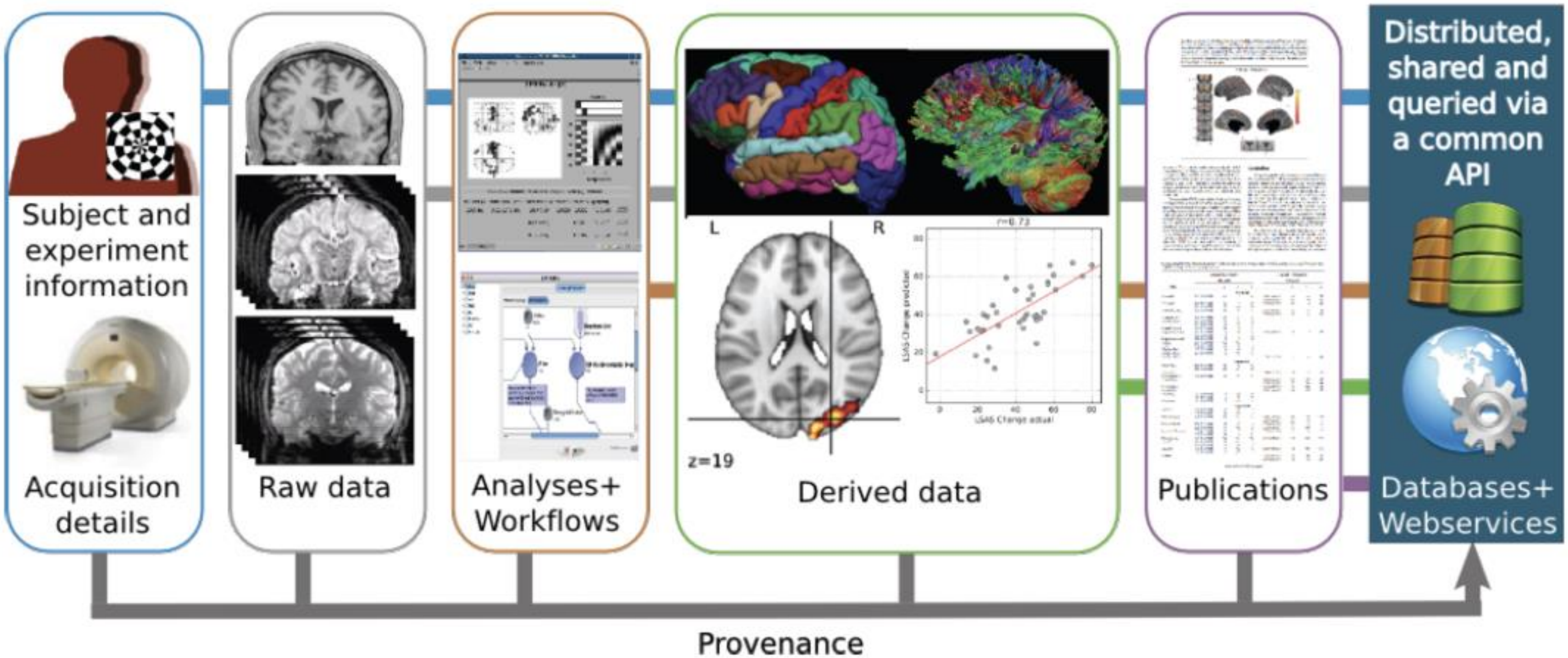


Sallet et al., *J Neuroscience* 2013

DTI defined
rsfcMRI

Wörsching et al., *NeuroImage* 2017
Wörsching et al., *Brain Stimulation* 2018
Bulubas et al., *Brain Stimulation* 2019
Mizutani et al., *NeuroImage Clinical 2022*
Chang et al., *NeuroImage 2024*

Dataflow in Brain Imaging

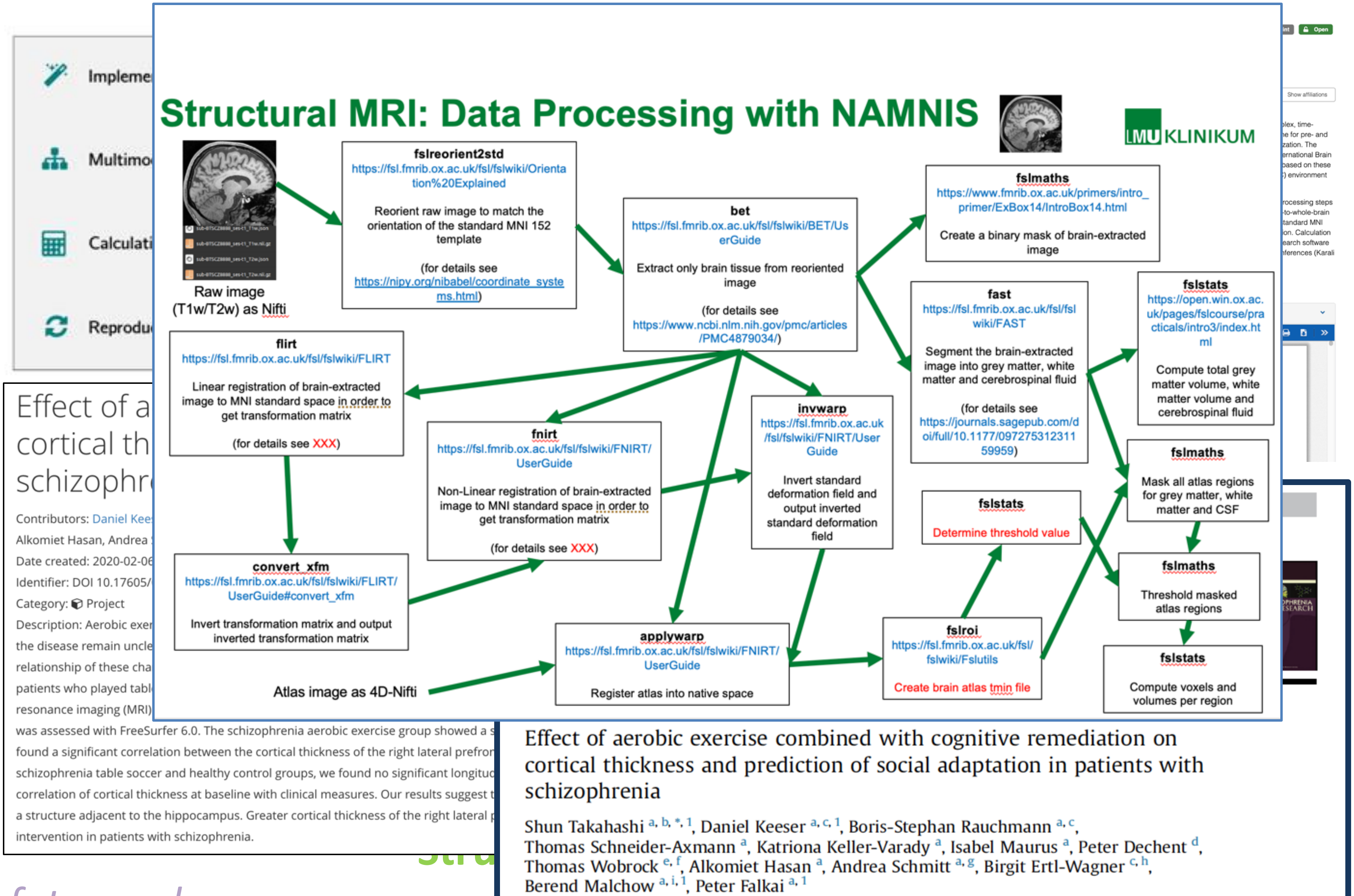


Subject and experiment information	Raw data	Analyses+ Workflows	Derived data	Publications	Databases+ Webservices
Demographics Stimuli Scanner Sequence Assays - Clinical - Neuropsych - Behavioral	MRI - T1 - T2 dMRI fMRI - Task - Resting EEG, MEG, PET, MRS	SPM FSL FreeSurfer AFNI ... Nipype LONI ... QA/QC	Contrasts Correlation Prediction	Journals Preprint archives Websites Blogs	XNAT IDA LORIS COINS Amazon S3 DropBox Globus Neurovault Neurosynth

Poline et al. 2011

5

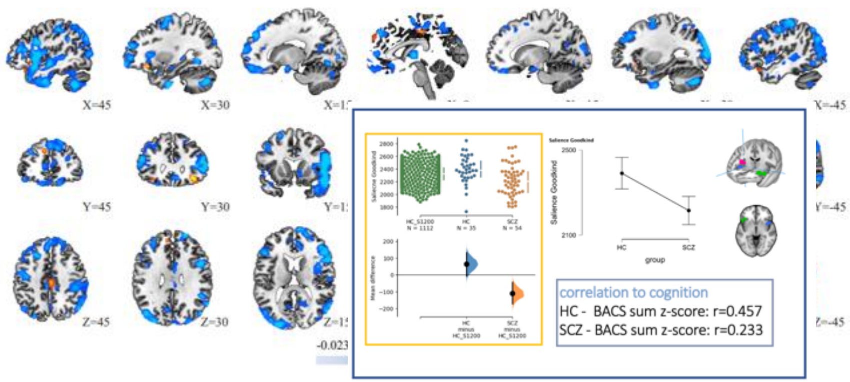
Neuromodulation **A**nd **M**ultimodal **N**euro**I**maging **s**cripts



future release

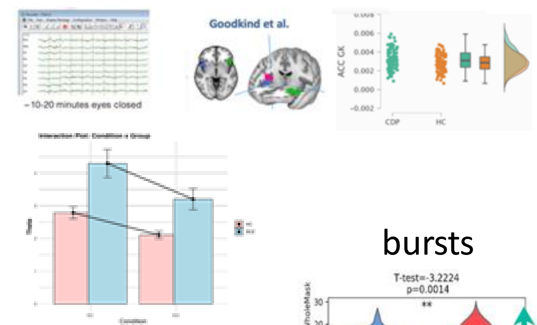
mMRI reduces variability outcome? CDP study as an example…

sMRI

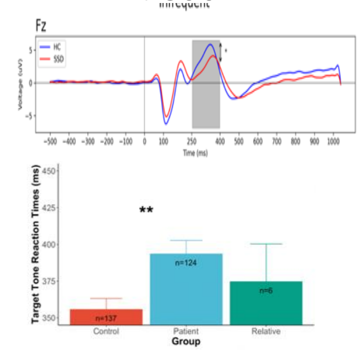


EEG

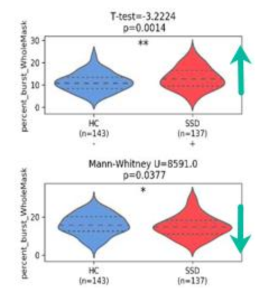
rsEEG



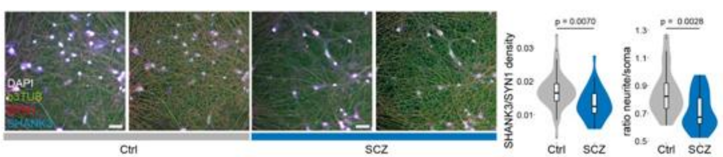
P300



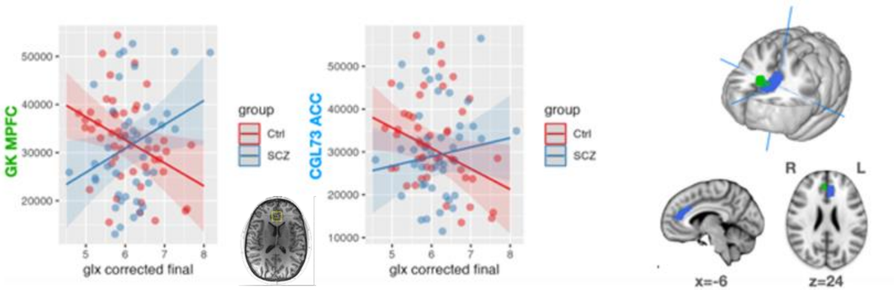
bursts

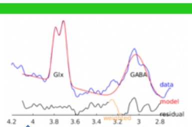
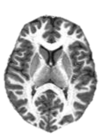
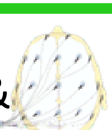


iPSC



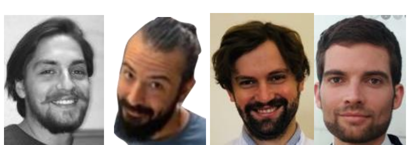
rsfMRI/MRS (subsample)



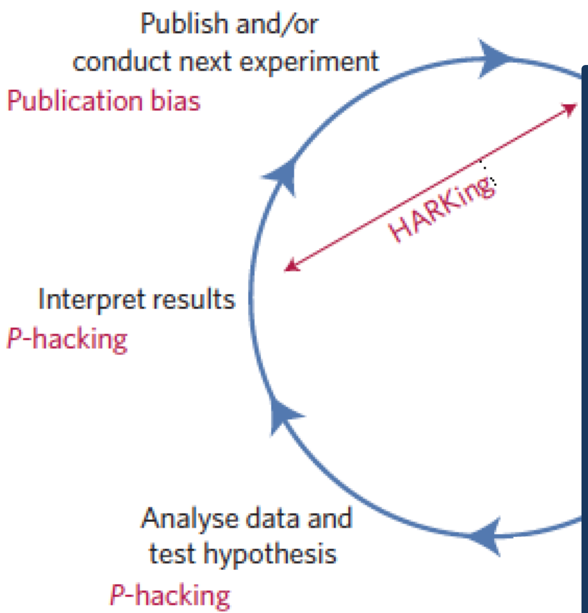

&

&


mechanistic insights

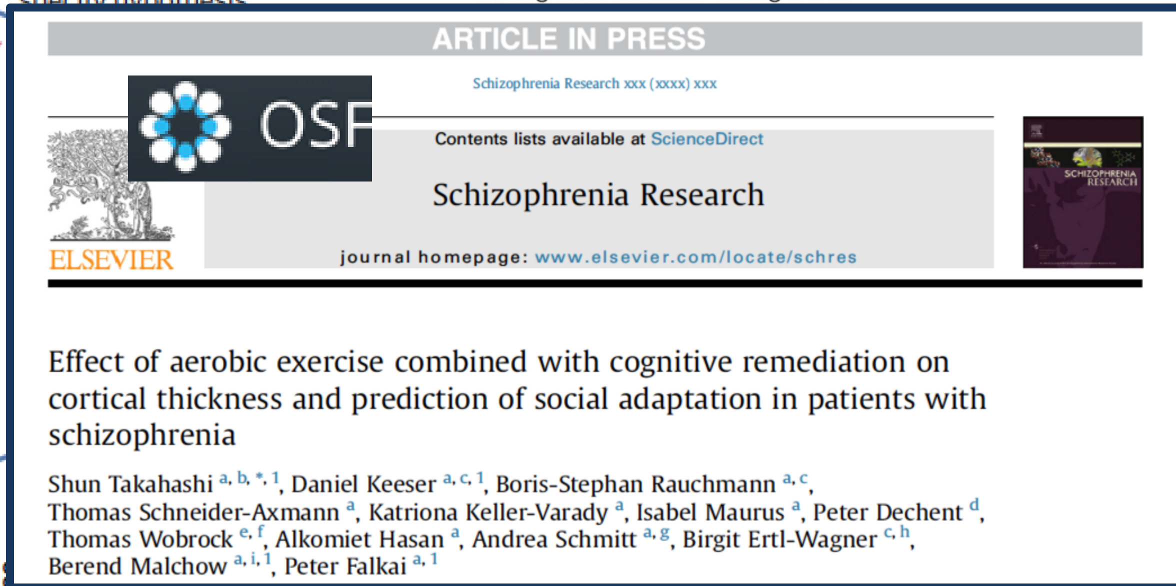
HC, N=287
SCZ, N=272



CDP: Krcmar et al., Frontiers in Psychiatry 2023
Raabe*, Hasanaj*, Karsli* et al, in Präparation



Munafo et al., Nature Hu



ARTICLE IN PRESS

Schizophrenia Research xxx (xxxx) xxx

OSF

Contents lists available at ScienceDirect

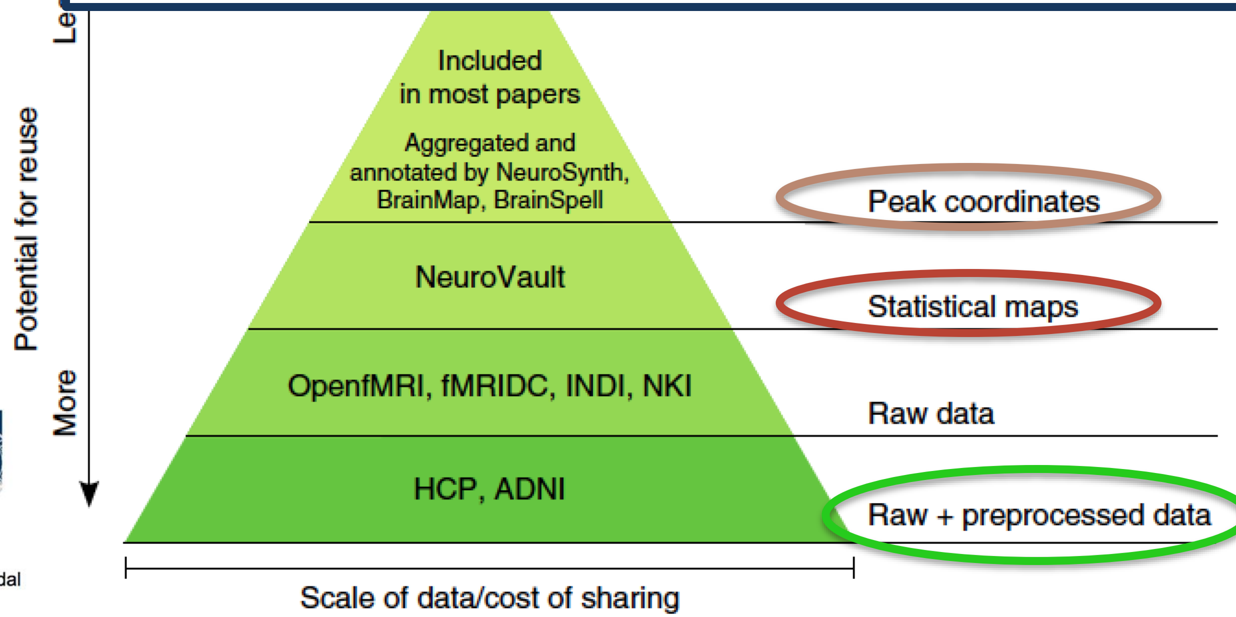
Schizophrenia Research

journal homepage: www.elsevier.com/locate/schres

ELSEVIER

Effect of aerobic exercise combined with cognitive remediation on cortical thickness and prediction of social adaptation in patients with schizophrenia

Shun Takahashi [a,b,*,1], Daniel Keeser [a,c,1], Boris-Stephan Rauchmann [a,c], Thomas Schneider-Axmann [a], Katriona Keller-Varady [a], Isabel Maurus [a], Peter Dechent [d], Thomas Wobrock [e,f], Alkomiet Hasan [a], Andrea Schmitt [a,g], Birgit Ertl-Wagner [c,h], Berend Malchow [a,i,1], Peter Falkai [a,1]



Poldrack & Gorgolewski, Nature Neuroscience 2014

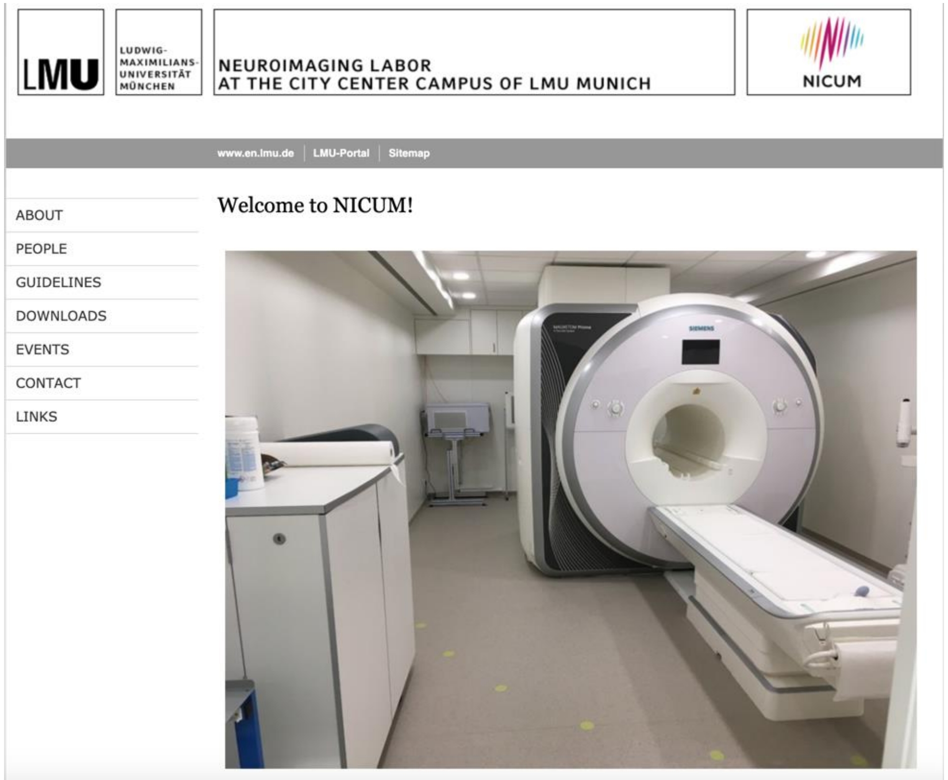
OSC
LMU Open Science Center

LMU KLINIKUM INTERDISCIPLINARY MULTIMODAL IMAGING GROUP

LMU - Klinikum der Universität München Interdisciplinary multimodal Imaging Group

NeuroImaging Core Unit Munich

NICUM



https://www.en.nicum.uni-muenchen.de/

www.neuroimaging-munich.de

Dept. of Psychiatry and Psychotherapy, University Hospital LMU, Head: Prof. Dr. Peter Falkai