Using the UK Biobank Imaging data

1st Australian UK Biobank Research Symposium
Brisbane, Australia 2024

Baptiste Couvy-Duchesne

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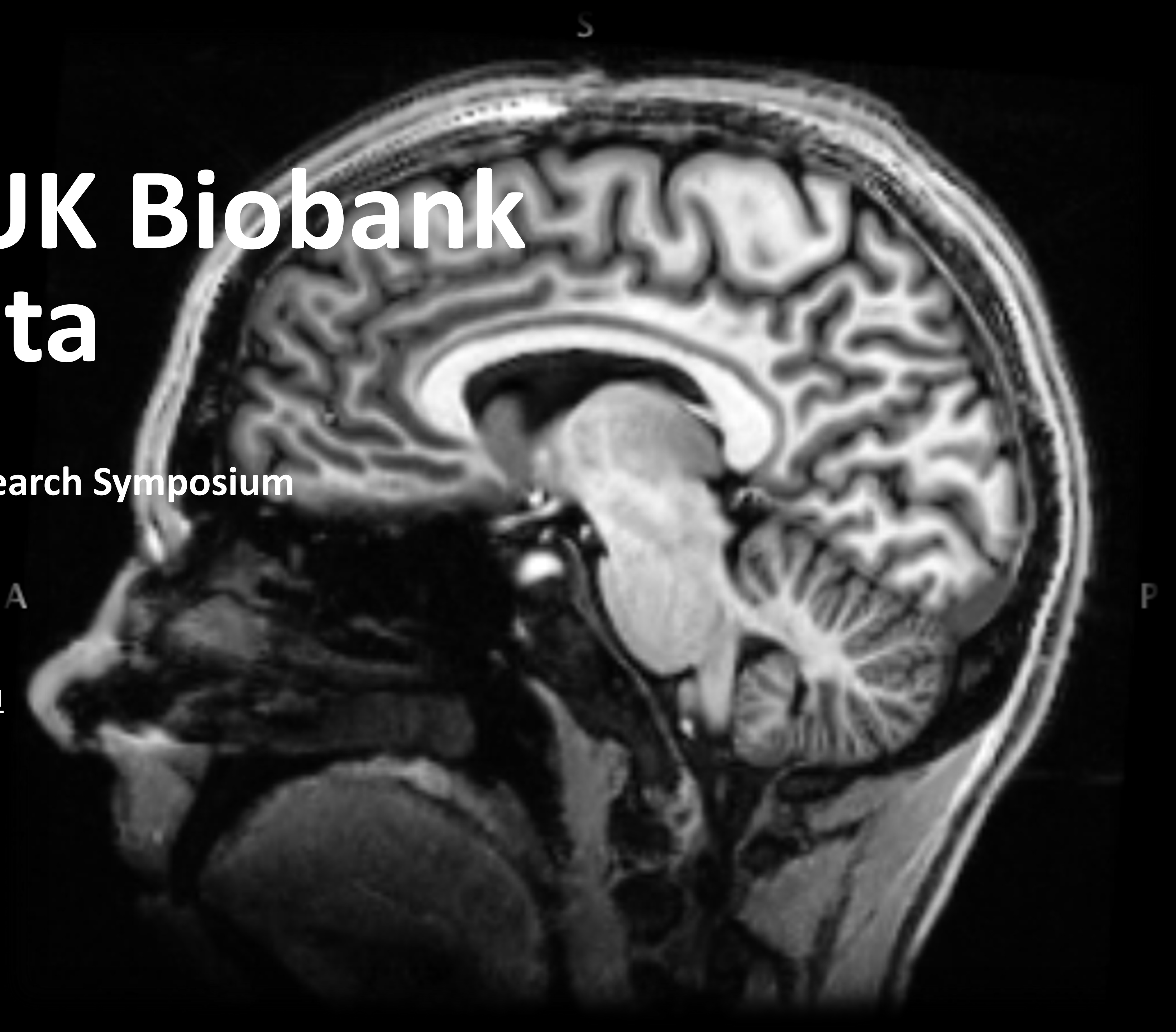
https://github.com/baptisteCD
@BaptisteCouvy



Overview of today's session

Introduction – and overview of the UKB imaging data

Baptiste Couvy-Duchesne

Focus on structural brain MRI (T1w)

Elise Delzant

Connectomes from brain data (structural and functional)

Caio Seguin

What does your imaging assessment visit involve?

The imaging assessment lasts around 4-5 hours and involves taking imaging scans of your internal organs and the collection of more information about your health and lifestyle, along with a small donation of blood.

https://www.ukbiobank.ac.uk/explore-your-participation/imaging-study-updates

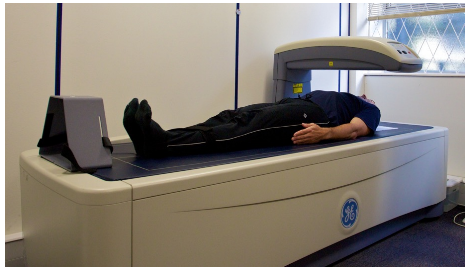
Repeat imaging – aiming for >60,000 individuals re-imaged

Summary of the Imaging visits

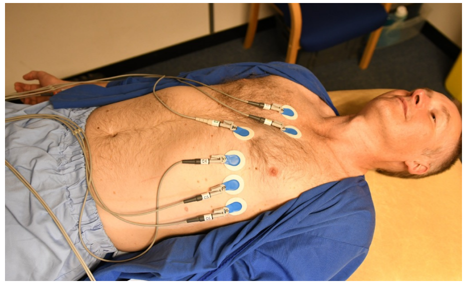
<u>MRI</u>
Brain
Heart
Abdominal/body

<u>Utrasound</u>
carodid

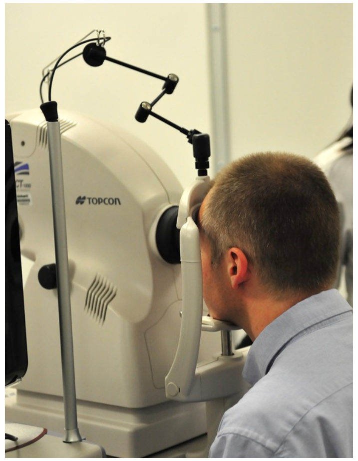
<u>Dual energy X ray (DXA)</u>
whole body



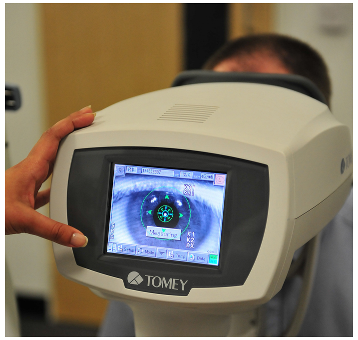
<u>Electrocardiogram (ECG)</u>
Heart



<u>Retinal optical coherence tomography *</u>



<u>Refractometry *</u>



* Brought back in repeat imaging session

Data types

Imaging derived phenotypes - IDPs

Bulk files

22677	Mean carotid IMT (intima-medial thickness) at 210 degrees	
22680	Mean carotid IMT (intima-medial thickness) at 240 degrees	
22670	Minimum carotid IMT (intima-medial thickness) at 120 degrees	
22673	Minimum carotid IMT (intima-medial thickness) at 150 degrees	
22676	Minimum carotid IMT (intima-medial thickness) at 210 degrees	
22679	Minimum carotid IMT (intima-medial thickness) at 240 degrees	
22682	Quality control indicator for IMT at 120 degrees	
22683	Quality control indicator for IMT at 150 degrees	
22684	Quality control indicator for IMT at 210 degrees	
22685	Quality control indicator for IMT at 240 degrees	
20222	Carotid artery ultrasound image (left)	‡
20223	Carotid artery ultrasound image (right)	‡
20226	Carotid artery ultrasound report	‡
20241	Raw carotid device data	‡

- 4 fields marked ‡ are blob/bulk.

Eye imaging

Eye measures – Refractometer

UK Biobank Eye and Vision Consortium

biobank uk

Index | Browse | Search | Catalogues | Downloads | Login | Help

Category 100014

Assessment centre ▸ Eye measures ▸ Refractometry ▸ Refractometer 1

Description

This category contains data on measurements related to the assessment of the participant's eye prescription (refractive error), using a TomeyRC - 5000 device. This category includes data on whether the measurement was made, and the test result for refractometry (Sphere, Cylinder, Axis, Pupil diameter) and keratometry (corneal refraction and astigmatism) for each eye. This measure was added to the assessment visit towards the end of recruitment and continued through the repeat visit in 2012.

Human Genetics (2018) 137:881–896
https://doi.org/10.1007/s00439-018-1942-8

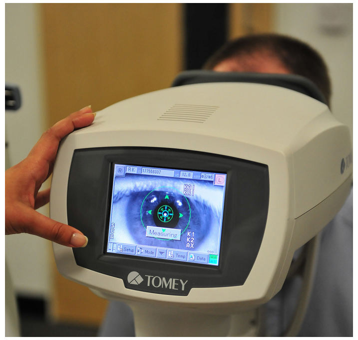
ORIGINAL INVESTIGATION

CrossMark

Genome-wide association studies for corneal and refractive astigmatism in UK Biobank demonstrate a shared role for myopia susceptibility loci

Rupal L. Shah[1] · Jeremy A. Guggenheim[1] · UK Biobank Eye and Vision Consortium

Received: 4 July 2018 / Accepted: 25 September 2018 / Published online: 10 October 2018



Eye measures - Retinal optical coherence tomography

biobank[uk]

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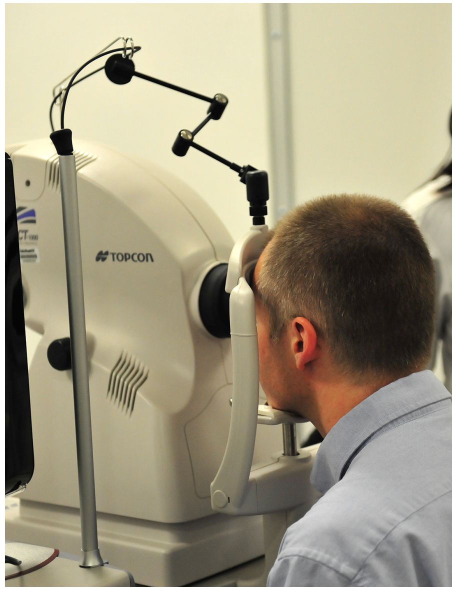
Category 100016

Assessment centre ▸ Eye measures ▸ Retinal optical coherence tomography

Description

This category contains data on optical imaging (Coherence Tomography) of the retina. The instrument takes a 3D scan and photograph of the retina and also provides a magnified photograph of the fundus. This category includes data on whether the measurement was performed, and imaging data of each eye.

This measure was added to the assessment visit towards the end of recruitment and also carried out during the initial re-assessment phase in 2012 using the TOPCON 3D OCT 1000 Mk2. It was not part of the standard imaging protocol but was re-introduced at the end of 2022 for participants being re-imaged using the TOPCON Triton device.



Age-related macular degeneration (AMD)
Glaucoma
Retinopathy.

Article | Open access | Published: 03 November 2022

UK Biobank retinal imaging grading: methodology, baseline characteristics and findings for common ocular diseases

Alasdair N. Warwick, Katie Curran, Barbra Hamill, Kelsey Stuart, Anthony P. Khawaja, Paul J. Foster, Andrew J. Lotery, Michael Quinn, Savita Madhusudhan, Konstantinos Balaskas, Tunde Peto & UKBB Eye and Vision Consortium

Eye **37**, 2109–2116 (2023) | Cite this article

Heart imaging

Heart measurements

biobank[uk]

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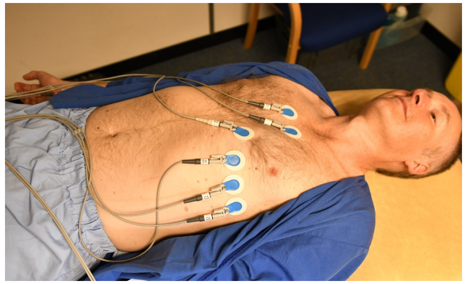
Category 104

Assessment centre ▸ Physical measures ▸ ECG at rest, 12-lead

Description

12-lead ECG



biobank[uk]

Category 102

Assessment centre ▸ Imaging ▸ Heart MRI

Description

Chest MRI imaging

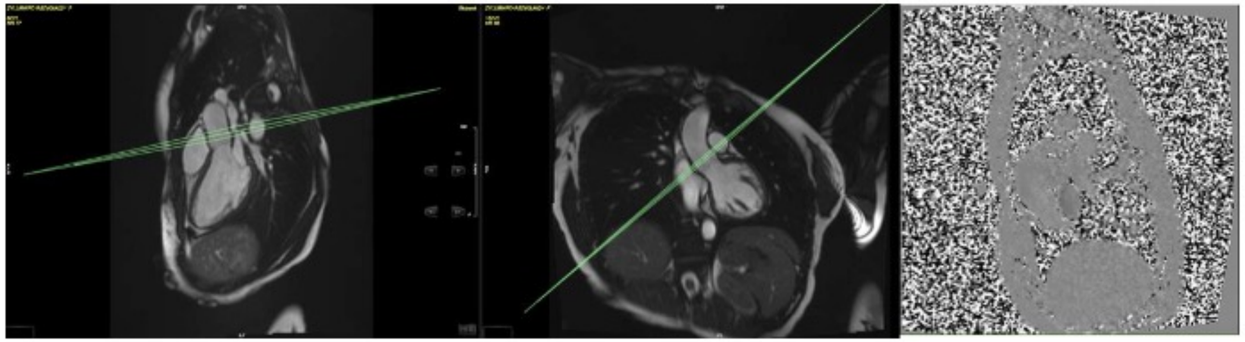


Figure 3: Aortic valve flow imaging view planned using the sagittal and coronal left ventricular outflow tract (LVOT) cines

https://biobank.ndph.ox.ac.uk/ukb/ukb/docs/cardiac_mri_explan.pdf

Heart (Chest) MRI

> Eur Heart J Cardiovasc Imaging. 2021 Feb 22;22(3):251-258. doi: 10.1093/ehjci/jeaa297.

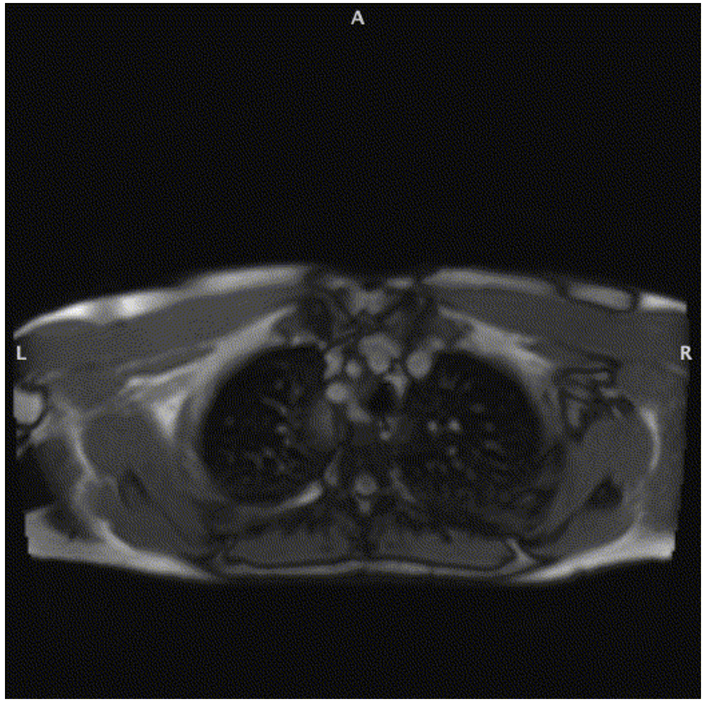
Cardiovascular magnetic resonance imaging in the UK Biobank: a major international health research resource

Zahra Raisi-Estabragh [1 2], Nicholas C Harvey [3 4], Stefan Neubauer [5], Steffen E Petersen [1 2]

Affiliations + expand

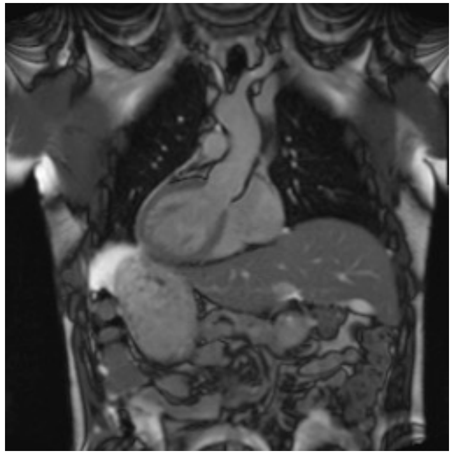
PMID: 33164079 PMCID: PMC7899275 DOI: 10.1093/ehjci/jeaa297

Free PMC article



A gif of one chest MRI

"The cardiovascular magnetic resonance (CMR) scan provides detailed assessment of **cardiac structure and function** comprising **bright blood anatomic assessment (sagittal, coronal, and axial), left and right ventricular cine images (long and short axes), myocardial tagging, native T1 mapping, aortic flow, and imaging of the thoracic aorta**"



JOURNAL ARTICLE

UK Biobank: opportunities for cardiovascular research

Thomas J Littlejohns ✉, Cathie Sudlow, Naomi E Allen, Rory Collins

European Heart Journal, Volume 40, Issue 14, 07 April 2019, Pages 1158–1166, https://doi.org/10.1093/eurheartj/ehx254

Published: 20 May 2017 **Article history** ▾

"**Classification and sub-classification of diseases** can be enhanced through combining the diverse phenotypic and genotypic data with medical records. The large sample size enables researchers to perform **risk stratification on well-defined phenotypes** to focus on **high- and low-risk populations for cardiovascular disease**, e.g. those with the lowest and highest levels of circulating lipid levels. Additionally, **mechanistic pathways between risk factors and outcomes can be explored using the genetic, biomarker and imaging data**."

Real-life heart monitoring

If you are 65 years or older at the time of your visit, we may also ask if you would be prepared to wear a heart monitoring patch for 14 days. This is a water-resistant adhesive patch that is applied to your skin over the heart and which will provide information on heart rhythm. We will give this to you when you visit us, together with a box so that you can return the device to us after the 14-day period.

Image of a heart monitor

From INFORMATION LEAFLET for participants

Irhythm or *Preventice* device –

Data restricted

biobank uk

Category 347

Additional exposures ▸ Cardiac monitoring

Description

Cardiac monitoring

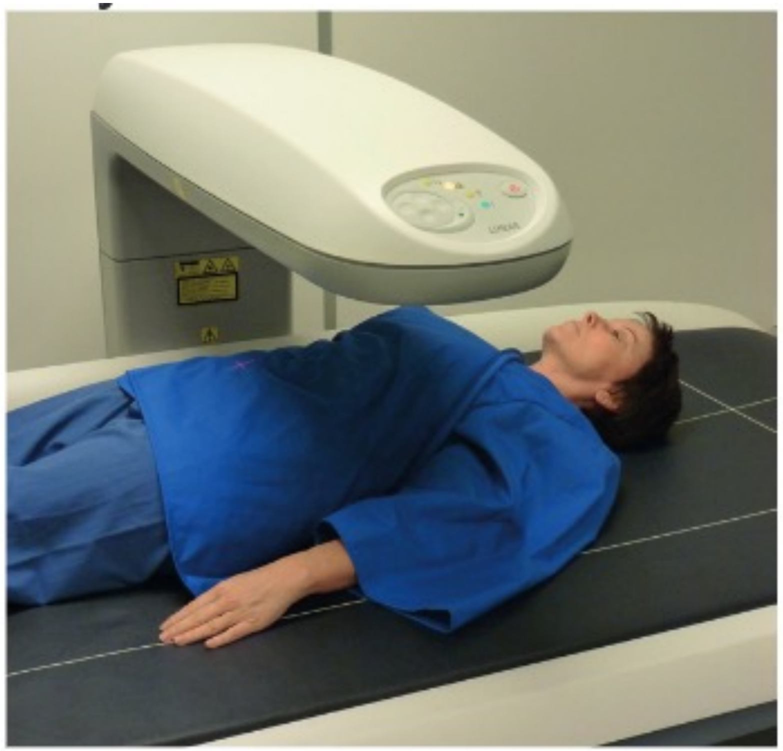
Body composition DXA scan

Bones and body composition - DXA

DXA (dual-energy X-ray absorptiometry) scan

- The DXA scan takes about 20 minutes.
- We will ask you to lie on a firm table while an arm of the scanner passes over you (see picture) to take X-ray images of your bones. We will ask you to lie in various positions so that the scanner can take images of different parts of your body.

From INFORMATION LEAFLET for participants



https://biobank.ctsu.ox.ac.uk/crystal/crystal/docs/DXA_explan_doc.pdf

Bones and body composition - DXA

Bone size, mineral content and density
Osteoarthritis
Bone mass
Fat mass
Lean mass
Fat percentage

Category 103

Assessment centre ▸ Imaging ▸ DXA assessment

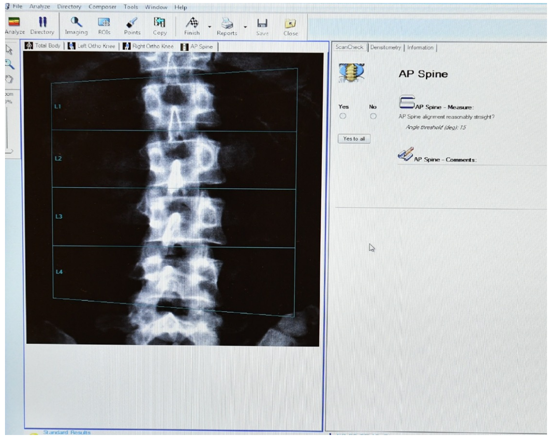
Description

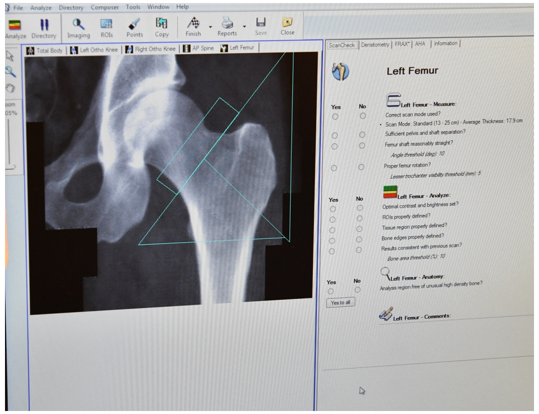
Whole body DXA imaging.

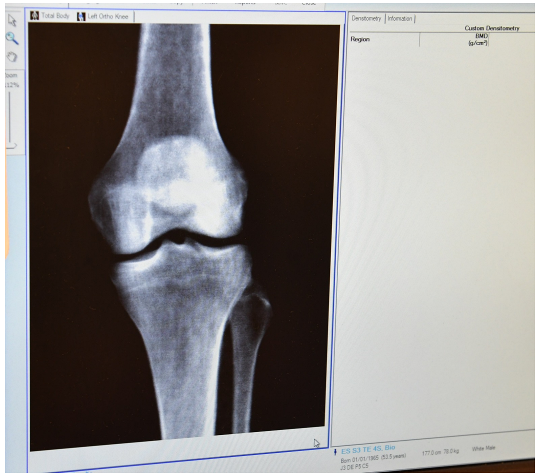
2 Sub-Categories | **5 Data-Fields** | **1 Parent Category**

Category ID	Description	Items
125	Bone size, mineral and density by DXA	120
124	Body composition by DXA	72

https://biobank.ctsu.ox.ac.uk/crystal/crystal/docs/DXA_explan_doc.pdf







Abdominal MRI

Abdominal (Body) MRI scan

biobank uk

Category 105

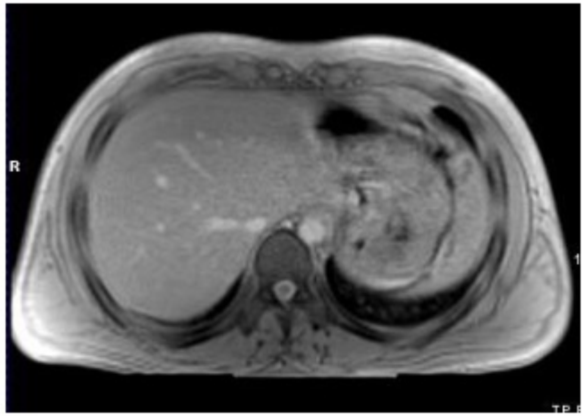
Assessment centre ▸ Imaging ▸ Abdominal MRI

Description

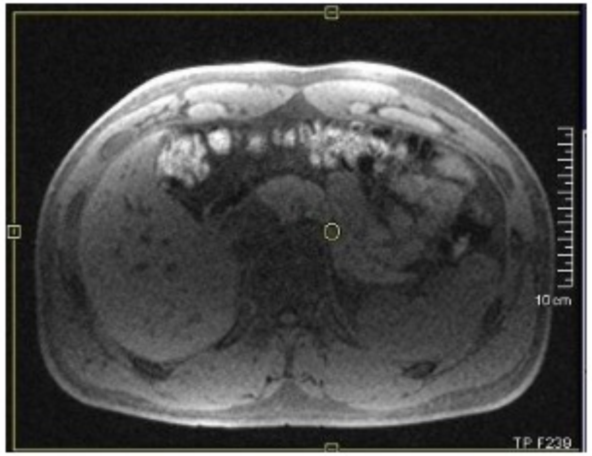
Abdominal MRI scans

5 Sub-Categories | **4 Data-Fields** | **1 Parent Ca**

Category ID	Description	Items
156	Kidney MRI	4+5
126	Liver MRI	7
131	Pancreas MRI	4
149	Abdominal composition	28
158	Abdominal organ composition	19



An axial image showing the liver at its maximum size on axial image



An axial fat sat image showing the pancreas

https://biobank.ctsu.ox.ac.uk/crystal/ukb/docs/body_mri_explan.pdf

Kidney

> Sci Rep. 2020 Dec 1;10(1):20963. doi: 10.1038/s41598-020-77981-4.

Kidney segmentation in neck-to-knee body MRI of 40,000 UK Biobank participants

Taro Langner [1], Andreas Östling [2], Lukas Maldonis [3], Albin Karlsson [2], Daniel Olmo [2], Dag Lindgren [3], Andreas Wallin [3], Lowe Lundin [3], Robin Strand [2 4], Håkan Ahlström [2 3], Joel Kullberg [2 3]

Affiliations + expand

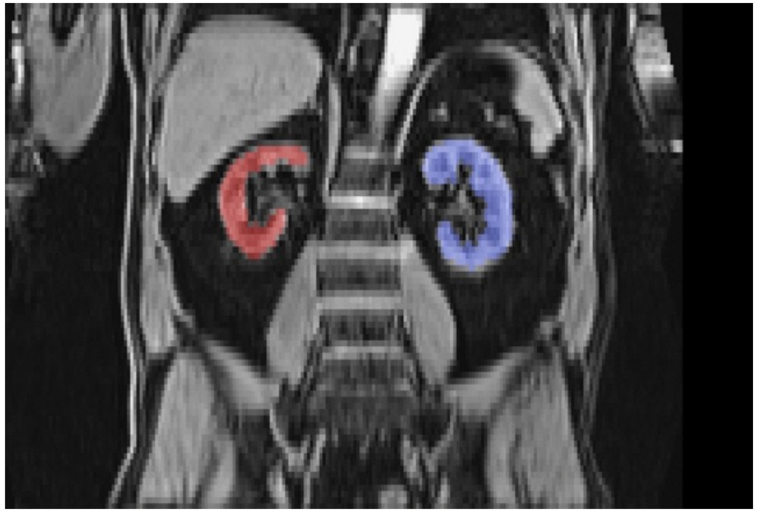
PMID: 33262432 PMCID: PMC7708493 DOI: 10.1038/s41598-020-77981-4

Free PMC article

Uppsala University, Sweden

5 Data-Fields | 1 Parent Category

Field ID	Description
21163	Kidney distance
21164	Kidney fusion
21161	Kidney parenchyma (left)
21162	Kidney parenchyma (right)
21160	Kidney parenchyma total



Liver

> PLoS One. 2017 Feb 27;12(2):e0172921. doi: 10.1371/journal.pone.0172921. eCollection 2017.

Characterisation of liver fat in the UK Biobank cohort

Henry R Wilman [1,2], Matt Kelly [1], Steve Garratt [3], Paul M Matthews [4], Matteo Milanesi [1], Amy Herlihy [1], Micheal Gyngell [1], Stefan Neubauer [1,5], Jimmy D Bell [2], Rajarshi Banerjee [1], E Louise Thomas [2]

Affiliations + expand

PMID: 28241076 PMCID: PMC5328634 DOI: 10.1371/journal.pone.0172921

Free PMC article

Reference range of liver corrected T1 values in a population at low risk for fatty liver disease–a UK Biobank sub-study, with an appendix of interesting cases

A Mojtahed [1], C J Kelly [2], A H Herlihy [2], S Kin [2], H R Wilman [2,3], A McKay [2], M Kelly [2], M Milanesi [2], S Neubauer [2,4], E L Thomas [3], J D Bell [3], R Banerjee [2], M Harisinghani [5]

Affiliations + expand

PMID: 30032383 PMCID: PMC6348264 DOI: 10.1007/s00261-018-1701-2

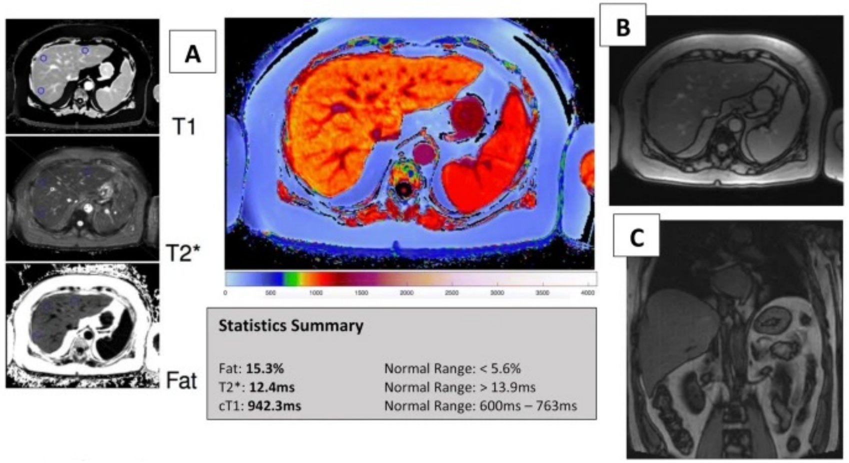
Free PMC article

7 Data-Fields | **1 Parent Category**

Field ID	Description	
20204	Liver Imaging - T1 ShMoLLI - DICOM	‡
20254	Liver imaging - IDEAL protocol - DICOM	‡
20203	Liver imaging - gradient echo - DICOM	‡
40061	Proton density fat fraction (PDFF)	
40062	Liver iron corrected T1 (ct1)	
40060	Liver iron (Fe)	
40063	Acquisition protocol	

- 3 fields marked ‡ are blob/bulk.

Patient 1



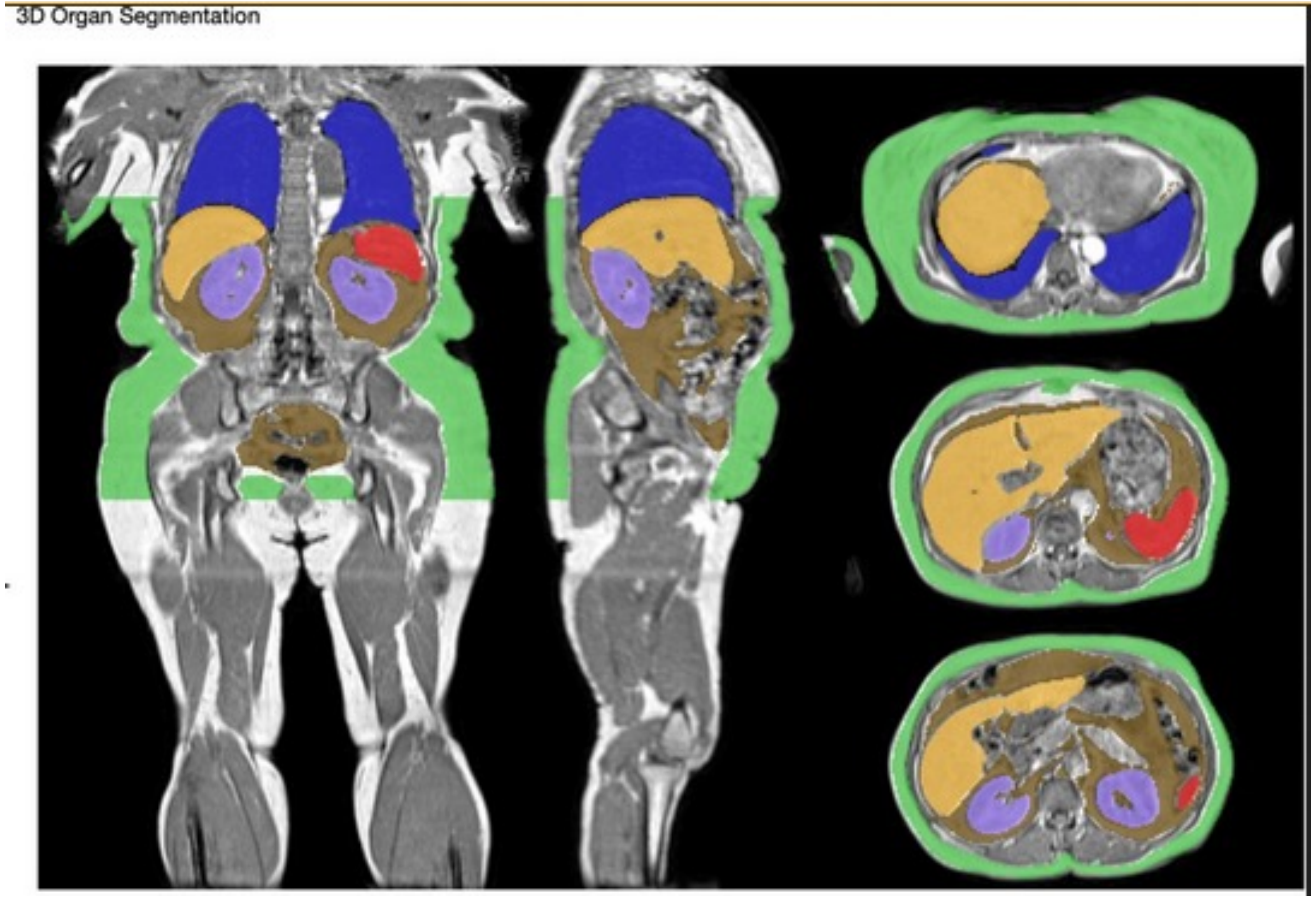
Abdominal composition

AMRA® Medical AB (Linköping, Sweden)

https://biobank.ctsu.ox.ac.uk/crystal/ukb/docs/AMRA_derived_explan_doc.pdf
https://biobank.ctsu.ox.ac.uk/crystal/label.cgi?id=149

Calico (Calico Life Sciences LLC, South San Francisco, USA) and the University of Westminster
https://biobank.ctsu.ox.ac.uk/crystal/label.cgi?id=158

Volume, fat, and iron in organs and tissues



> Elife. 2021 Jun 15:10:e65554. doi: 10.7554/eLife.65554.

Genetic architecture of 11 organ traits derived from abdominal MRI using deep learning

Yi Liu [1], Nicolas Basty [2], Brandon Whitcher [2], Jimmy D Bell [2], Elena P Sorokin [1], Nick van Bruggen [1], E Louise Thomas [# 2], Madeleine Cule [# 1]

Affiliations + expand

PMID: 34128465 PMCID: PMC8205492 DOI: 10.7554/eLife.65554

Free PMC article

Carotid ultrasound

Carotid ultrasound

Left and right measurements
Manual + automated measurements
Quality control
Artery intima-media thickness (cIMT) is a marker of subclinical **atherosclerosis** (build-up of cholesterol plaque in the walls of arteries)

https://biobank.ndph.ox.ac.uk/ukb/ukb/docs/carult_explan_doc.pdf

Journal Article

Arterioscler Thromb Vasc Biol. 2022 Apr; 42(4): 484–501.
Published online 2021 Dec 2. doi: 10.1161/ATVBAHA.121.317007
PMCID: PMC8939707
PMID: 34852643

Twenty-Five Novel Loci for Carotid Intima-Media Thickness: A Genome-Wide Association Study in >45 000 Individuals and Meta-Analysis of >100 000 Individuals

Ming Wai Yeung,[1] Siqi Wang,[3,1,2] Yordi J. van de Vegte,[1] Oleg Borisov,[4] Jessica van Setten,[2] Harold Snieder,[2] Niek Verweij,[1] M. Abdullah Said,[1] and Pim van der Harst✉[1,3]

▸ Author information ▸ Article notes ▸ Copyright and License information PMC Disclaimer

Brain MRI

Brain MRI

Notes | 9 Sub-Categories | 5 Data-Fields | 1 Parent Category

Category ID	Description	Items
108	Scout images and configuration for brain MRI	2
110	T1 structural brain MRI	26+1425
112	T2-weighted brain MRI	8
119	Arterial spin labelling brain MRI	52
106	Task functional brain MRI	34
107	Diffusion brain MRI	14+684
111	Resting functional brain MRI	48+6
109	Susceptibility weighted brain MRI	38
200	Native atlases	1+13

Bulk files – raw and processed images
>3,000 IDPs (Imaging Derived Phenotypes)

Brain MRI – must read

Resource | Published: 19 September 2016

Multimodal population brain imaging in the UK Biobank prospective epidemiological study

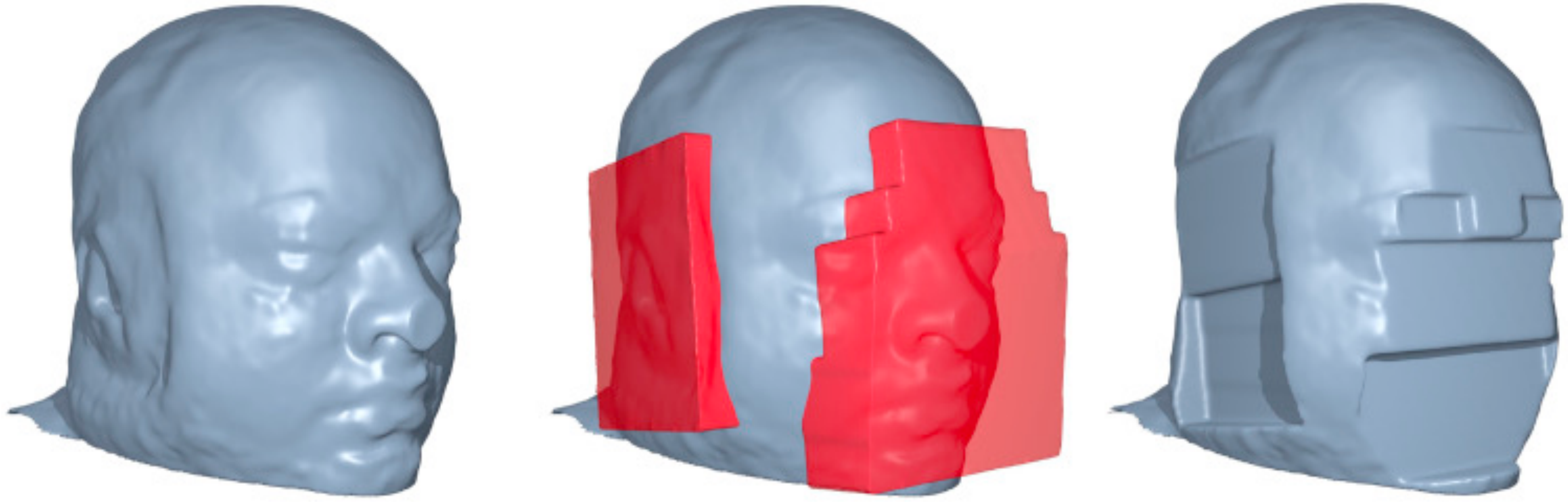
Karla L Miller, Fidel Alfaro-Almagro, Neal K Bangerter, David L Thomas, Essa Yacoub, Junqian Xu, Andreas J Bartsch, Saad Jbabdi, Stamatios N Sotiropoulos, Jesper L R Andersson, Ludovica Griffanti, Gwenaëlle Douaud, Thomas W Okell, Peter Weale, Iulius Dragonu, Steve Garratt, Sarah Hudson, Rory Collins, Mark Jenkinson, Paul M Matthews & Stephen M Smith

Nature Neuroscience **19**, 1523–1536 (2016) | Cite this article

Brain Imaging Documentation

https://biobank.ndph.ox.ac.uk/ukb/ukb/docs/brain_mri.pdf

Brain MRI – defacing & processing



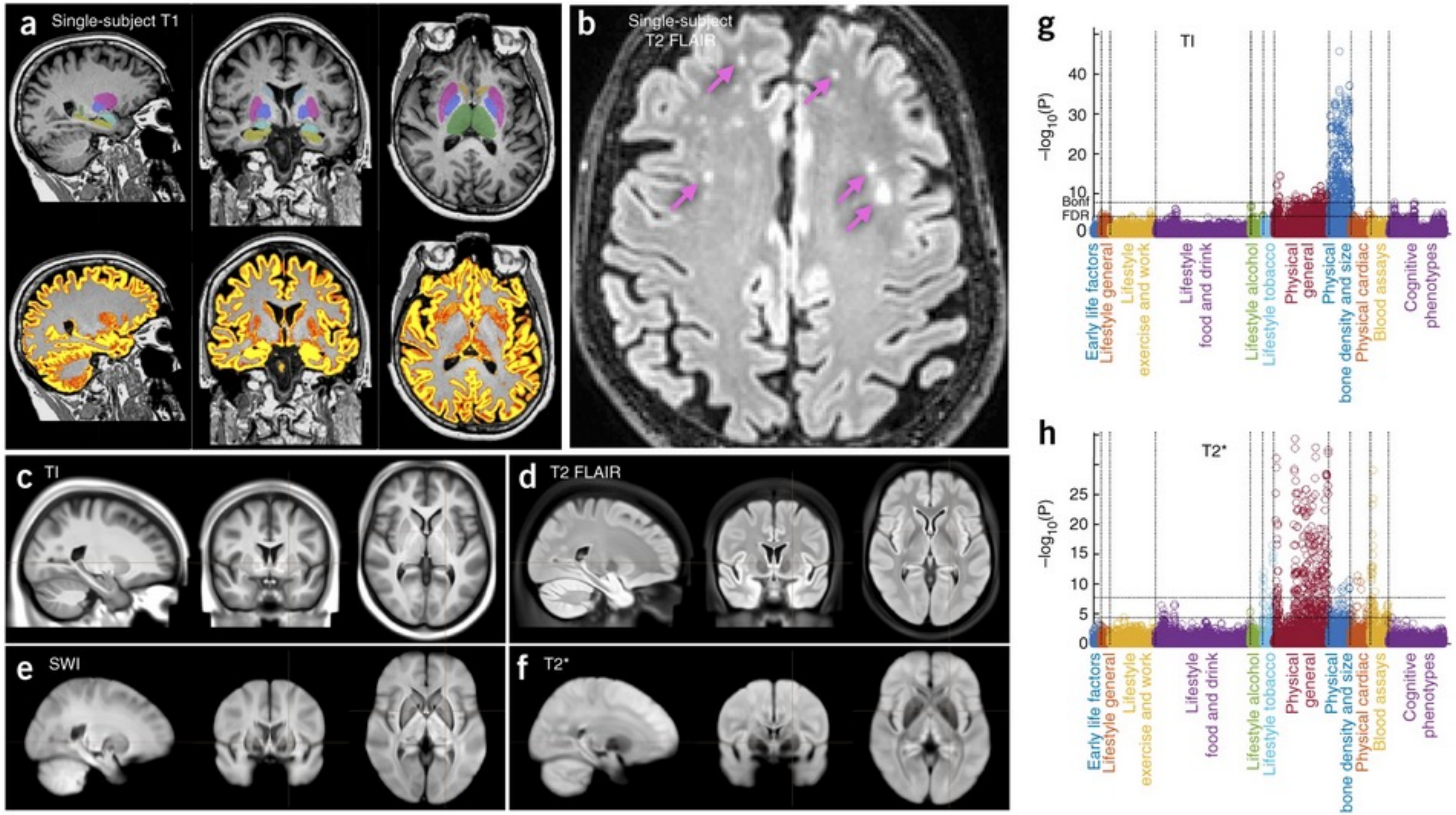
› Neuroimage. 2018 Feb 1:166:400-424. doi: 10.1016/j.neuroimage.2017.10.034.
Epub 2017 Oct 24.

Image processing and Quality Control for the first 10,000 brain imaging datasets from UK Biobank

Fidel Alfaro-Almagro [1], Mark Jenkinson [2], Neal K Bangerter [3], Jesper L R Andersson [2], Ludovica Griffanti [2], Gwenaëlle Douaud [2], Stamatios N Sotiropoulos [4], Saad Jbabdi [2], Moises Hernandez-Fernandez [2], Emmanuel Vallee [2], Diego Vidaurre [5], Matthew Webster [2], Paul McCarthy [2], Christopher Rorden [6], Alessandro Daducci [7], Daniel C Alexander [8], Hui Zhang [8], Iulius Dragonu [9], Paul M Matthews [10], Karla L Miller [2], Stephen M Smith [2]

Non-defaced MRI accessible upon request – restricted field

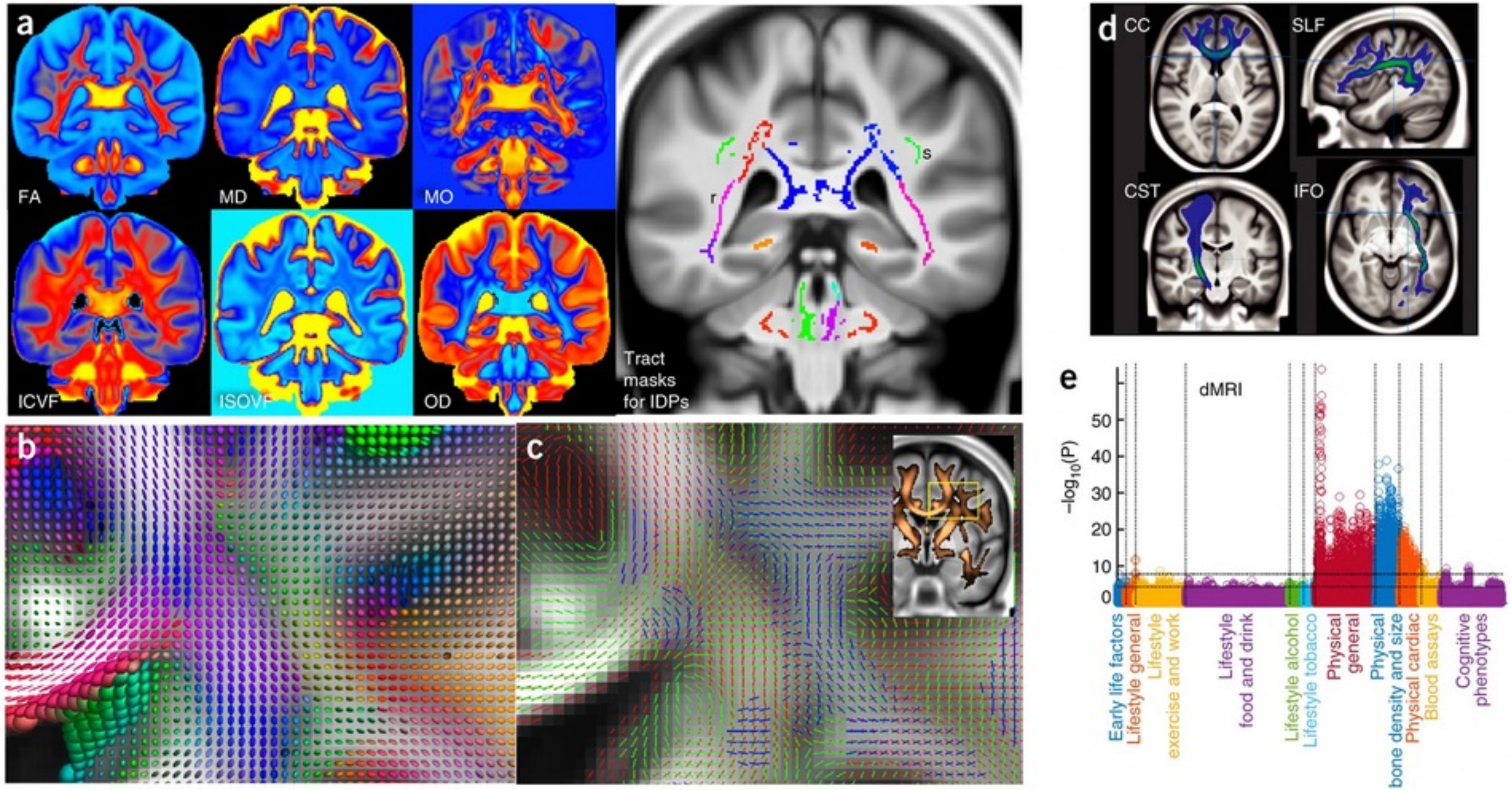
Structural Brain MRI – T1w, T2-FLAIR, SWI



(**g**) Manhattan plot (a layout common in genetic studies) relating all 25 IDPs from the T1 data to 1,100 non-brain-imaging variables extracted from the UK Biobank database. Effects such as age, sex and head size are regressed out of all data before computing the correlations. Here, the maximum r^2 = 0.045 and the minimum r^2 = 0.0058. (**h**) Plot relating all 14 T2* IDPs to 1,100 non-imaging variables. Maximum r^2 = 0.034, minimum r^2 = 0.0063. Marked Bonferroni and FDR multiple comparison threshold levels are presented as in **g**.

[Multimodal population brain imaging in the UK Biobank prospective epidemiological study]

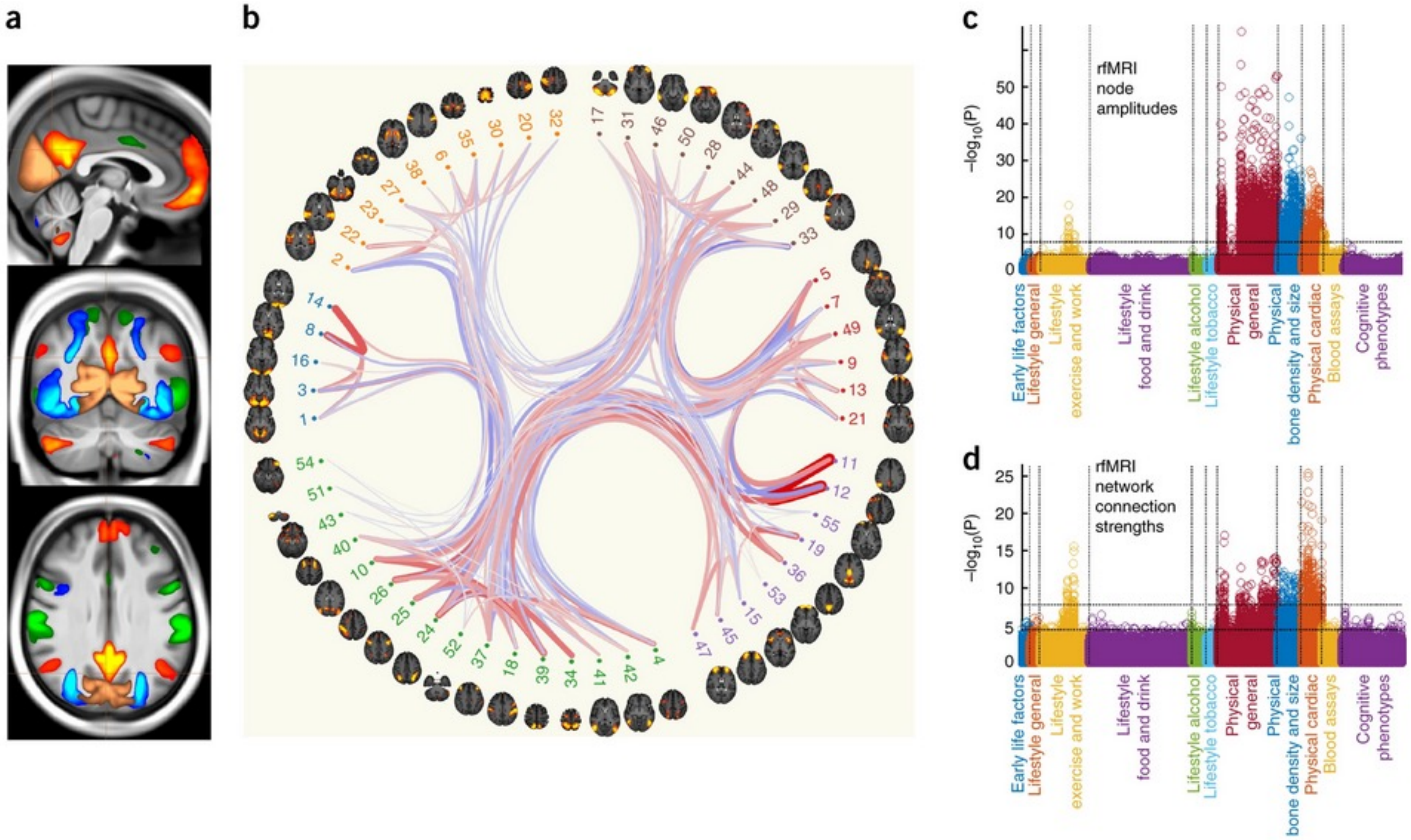
Diffusion Brain MRI



(**e**) Plot relating all 675 dMRI IDPs (nine distinct dMRI modeling outputs from tensor and NODDI models × 75 tract masks) to 1,100 non-imaging variables (see Fig. 1g for details). Maximum r^2 = 0.057, minimum r^2 (passing Bonferroni) = 0.0065. Dotted horizontal lines (multiple comparison thresholds) are described in Figure 1g.

Multimodal population brain imaging in the UK Biobank prospective epidemiological study

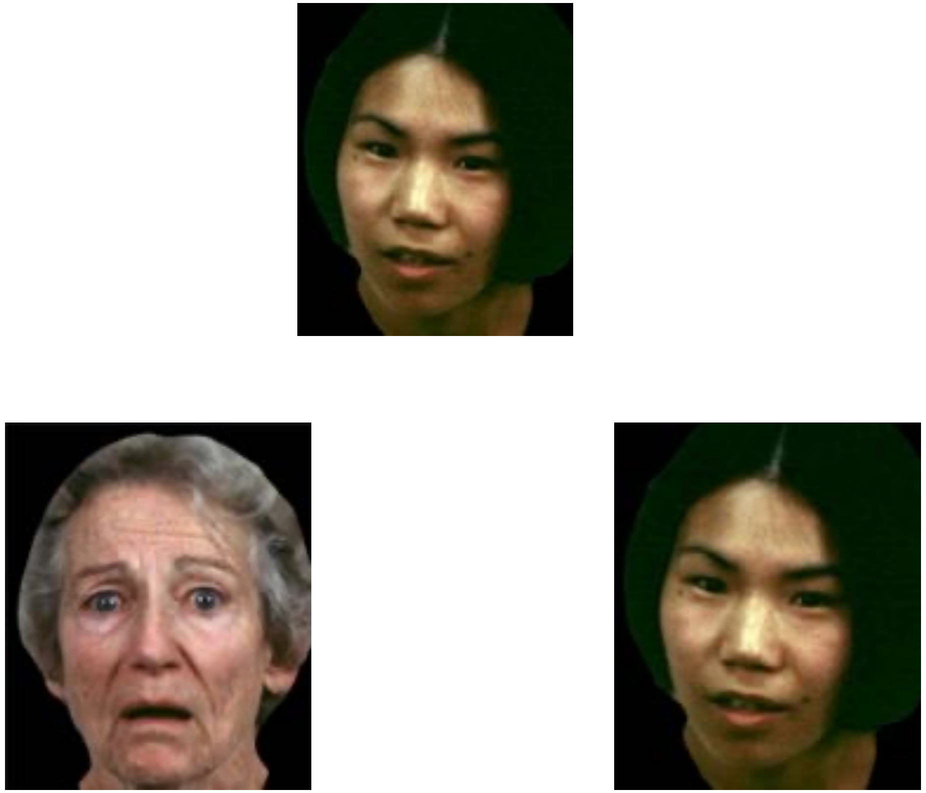
Resting-state fMRI



(**c**) Plot relating the 76 rfMRI 'node amplitude' IDPs to 1,100 non-imaging variables (see Fig. 1g for details). Maximum r^2 = 0.065, minimum r^2 (passing Bonferroni) = 0.0059. (**d**) Plot relating the 1,695 rfMRI 'functional connectivity' IDPs to 1,100 non-imaging variables. Maximum r^2 = 0.032, minimum r^2 = 0.0059. Dotted horizontal lines (multiple comparison thresholds) in **c** and **d** are described in Figure 1g.

Multimodal population brain imaging in the UK Biobank prospective epidemiological study

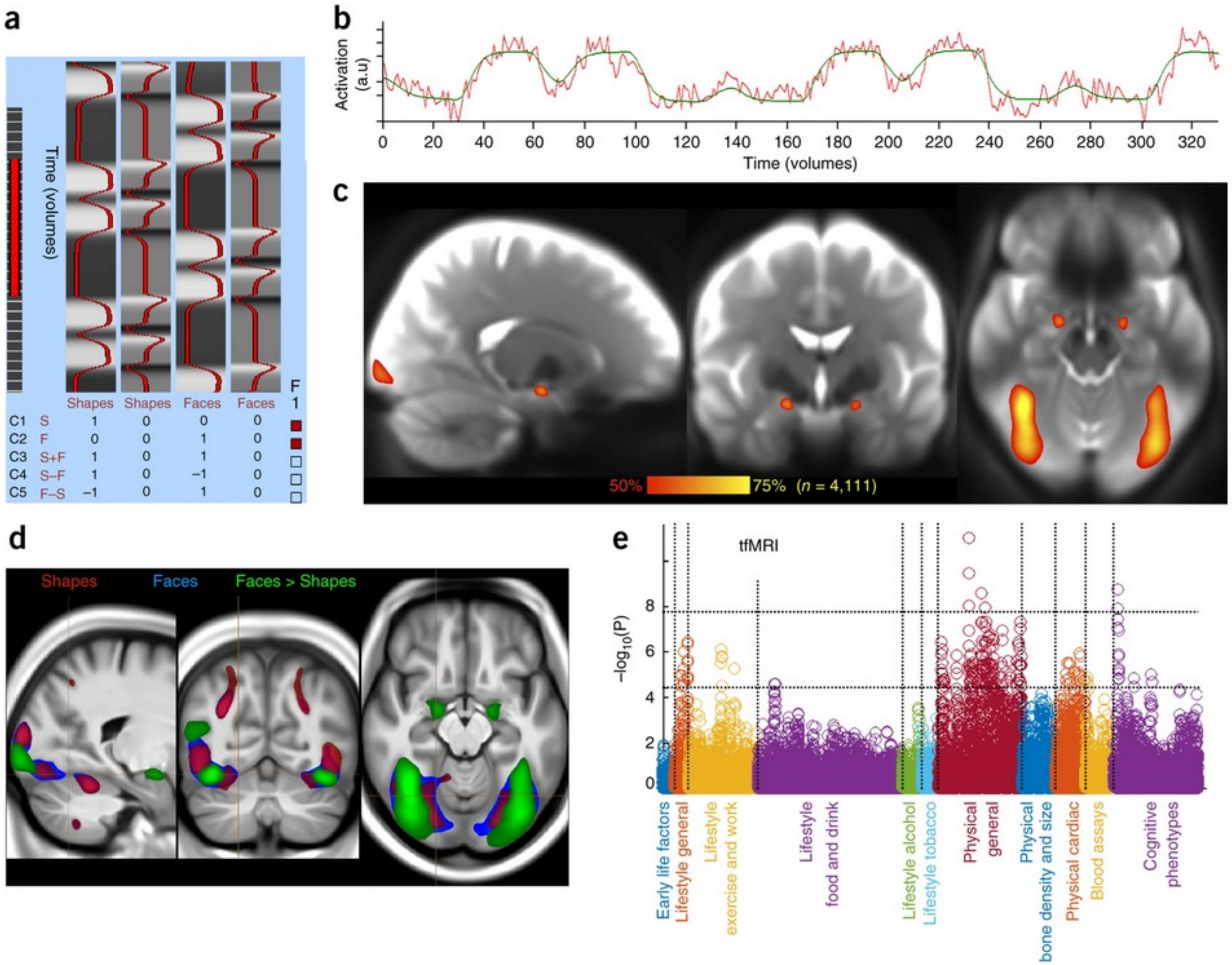
Task fMRI – Emotion processing



Hariri faces/shapes "emotion" task
The participants are presented with blocks of trials and asked to decide either which of two faces presented on the bottom of the screen match the face at the top of the screen, or which of two shapes presented at the bottom of the screen match the shape at the top of the screen. The faces have either angry or fearful expressions.

Emotion processing
Visual regions
Face recognition

Task fMRI – Emotion processing



(**e**) Plot relating the 16 tfMRI IDPs to 1,100 non-imaging variables (see Fig. 1g for details). Maximum r^2 = 0.018, minimum r^2 (passing Bonferroni) = 0.0062. Dotted horizontal lines (multiple comparison thresholds) are described in Figure 1g.

GWAS of brain IDPs

Article | Open access | Published: 10 October 2018

Genome-wide association studies of brain imaging phenotypes in UK Biobank

Lloyd T. Elliott, Kevin Sharp, Fidel Alfaro-Almagro, Sinan Shi, Karla L. Miller, Gwenaëlle Douaud, Jonathan Marchini & Stephen M. Smith

Nature 562, 210–216 (2018) | Cite this article

75k Accesses | 349 Citations | 204 Altmetric | Metrics

2018
3,144 brain IDPs
N=8,428 participants

Nat Neurosci. Author manuscript; available in PMC 2021 May 9.
Published in final edited form as:
Nat Neurosci. 2021 May 1; 24(5): 737–745.
Published online 2021 Apr 19. doi: 10.1038/s41593-021-00826-4

PMCID: PMC7610742
EMSID: EMS123172
PMID: 33875891

An expanded set of genome-wide association studies of brain imaging phenotypes in UK Biobank

Stephen M Smith,[1] Gwenaëlle Douaud,[1] Winfield Chen,[2] Taylor Hanayik,[1] Fidel Alfaro-Almagro,[1] Kevin Sharp,[3] and Lloyd T Elliott[2,*]

2021
3,935 brain IDPs
N=39,691 participants

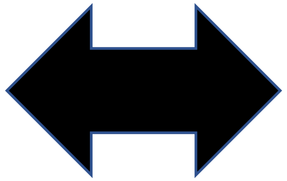
Tips about getting started with UK Biobank images

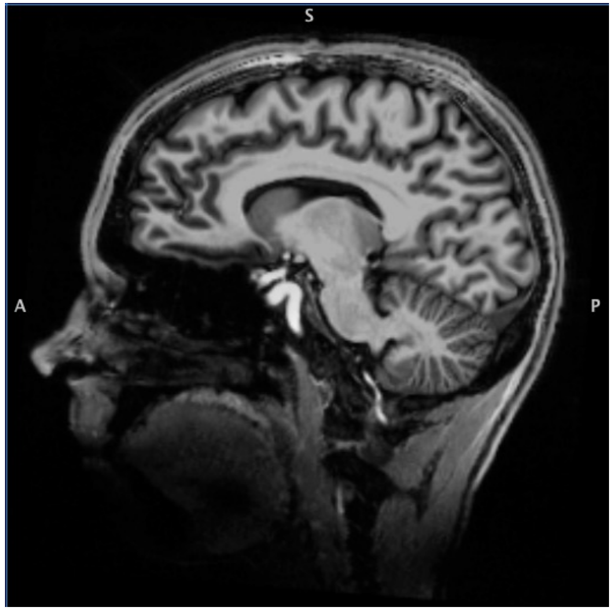
Some tips

- Check overlap between trait/disease of interest and imaging sessions
- Read specific documentation about imaging of interest
- Explore data returned by other research groups
- Are available IDPs enough for the analysis ?
- Do you need bulk files ?
- If bulk – need resources – e.g. High Performance Cluster, RAP
- Imaging expert for processing / analyses
- Keep in mind returning data to UK Biobank

From IDPs to vertex/voxel wise analyses

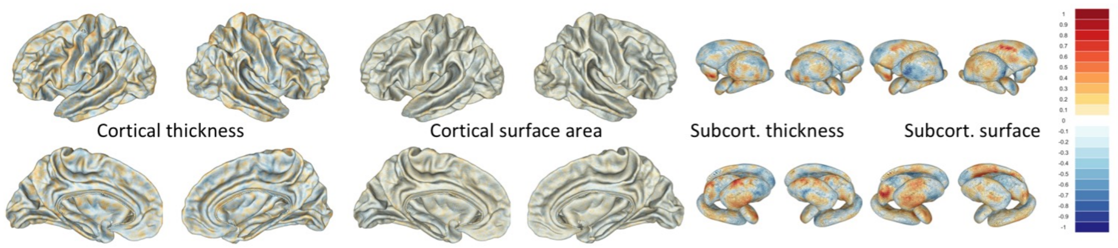
Starting point





- **High dimensional**
  - 10M common SNPs
  - 1M cortical structure measurements)

- **Complex pattern of correlation** (LD / connectome) biobank uk



Z : Vertex-wise measurements (standardised)

p ~ 650,000 measurements per individual

Y : Phenotypes

Demographics, Blood-assay, Cognition, Diet, Lifestyle, Activity levels, Substance use, Traumas/Stress, Mental health

X : Covariates

Age, sex, ICV, Body size

$$\mathbf{Y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \mathbf{e}$$

$$\mathbf{u} \sim \mathcal{N}\left(0, \boldsymbol{I}\sigma_b^2/\boldsymbol{p}\right)$$

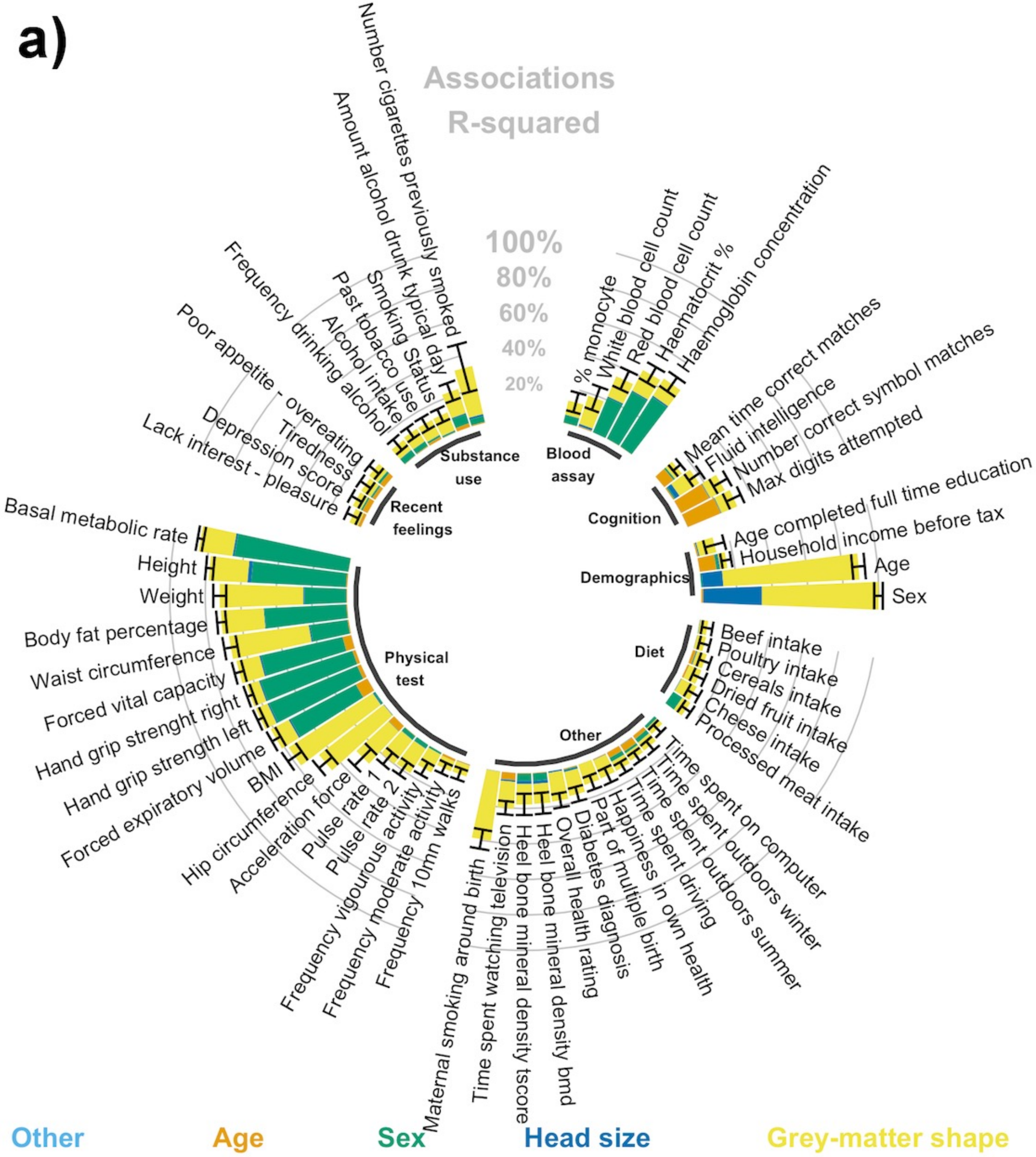
Morphometricity

$$m^2 = \frac{\widehat{\sigma_b^2}}{(\widehat{\sigma_b^2} + \widehat{\sigma_e^2})}$$

- Total association with vertex-wise data
- Information contained in brain image

A unified framework for association and prediction from vertex-wise grey-matter structure, Couvy-Duchesne et al., Human Brain Mapping, 2020

a)



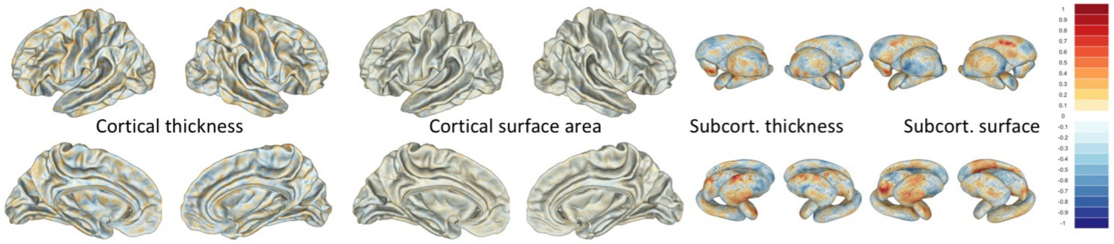
Morphometricity

N=8,662 UKB participants
M~650,000 brain measurements
168 phenotypes tested

- **58 with significant morphometricity**

A unified framework for association and prediction from vertex-wise grey-matter structure, Couvy-Duchesne et al., Human Brain Mapping, 2020

Applications to compare MRI processing
Furtjes et al., Cortex, 2023
Delzant et al., in preparation



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Grey-matter correlation

$$r_{GM}$$

Bivariate LMM

- Shared morphometricity between traits

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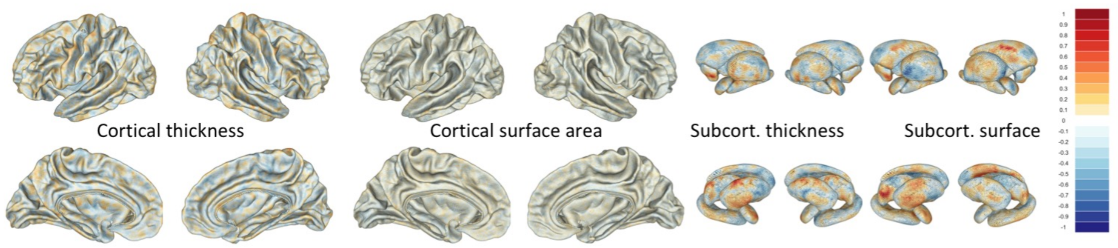

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$$\mathbf{Y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \mathbf{e}$$

$$\mathbf{u} \sim \mathcal{N}\left(0, \boldsymbol{I}\sigma_b^2/\boldsymbol{p}\right)$$

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Best Linear Unbiased Prediction (BLUP)

$$\widehat{Y} = \mathbf{Z}\widehat{u}$$

- Normal distribution of association ($\mathbf{u}$) across vertices
- Prediction in independent samples

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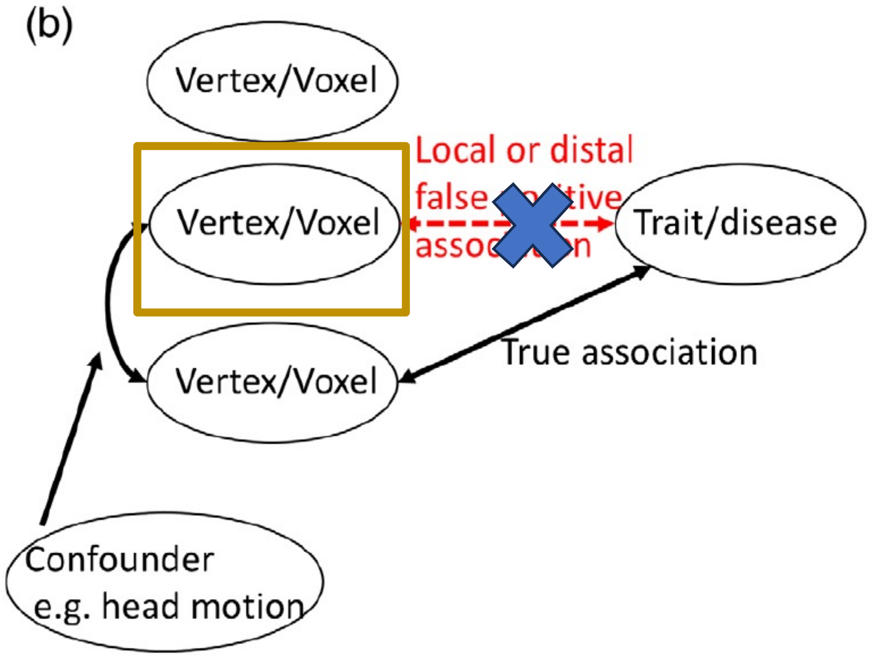
HUMAN Connectome PROJECT

A unified framework for association and prediction from vertex-wise grey-matter structure, Couvy-Duchesne et al., Human Brain Mapping, 2020

Brain-mapping models

$$\mathbf{Y} = \mathbf{X}_i b_i + \mathbf{Zc} + \boldsymbol{\varepsilon}$$ GLM

$$\mathbf{Y} = \mathbf{X}_i \mathrm{b}_i + \mathbf{Zc} + \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon}$$ LMM



$\boldsymbol{X}$: Nxp matrix of all standardised vertex-wise measurements,
$\boldsymbol{Z}$ **:** Nxq of q covariates
$\boldsymbol{c}$: the q fixed effects
$\boldsymbol{\beta}$: vector of joint vertex-trait associations, random effects, allowing for p>N, with $\boldsymbol{\beta} \sim \mathcal{N}(0, \mathbf{I}\sigma^2_{\boldsymbol{\beta}})$
$\boldsymbol{\varepsilon}$: error term assumed to follow $\boldsymbol{\varepsilon} \sim \mathcal{N}(0, \mathbf{I}\sigma^2_{\boldsymbol{\varepsilon}})$.
$\sigma^2_{\boldsymbol{\beta}}$ and $\sigma^2_{\boldsymbol{\varepsilon}}$: the variances of the random effects $\boldsymbol{\beta}$ and $\boldsymbol{\varepsilon}$.

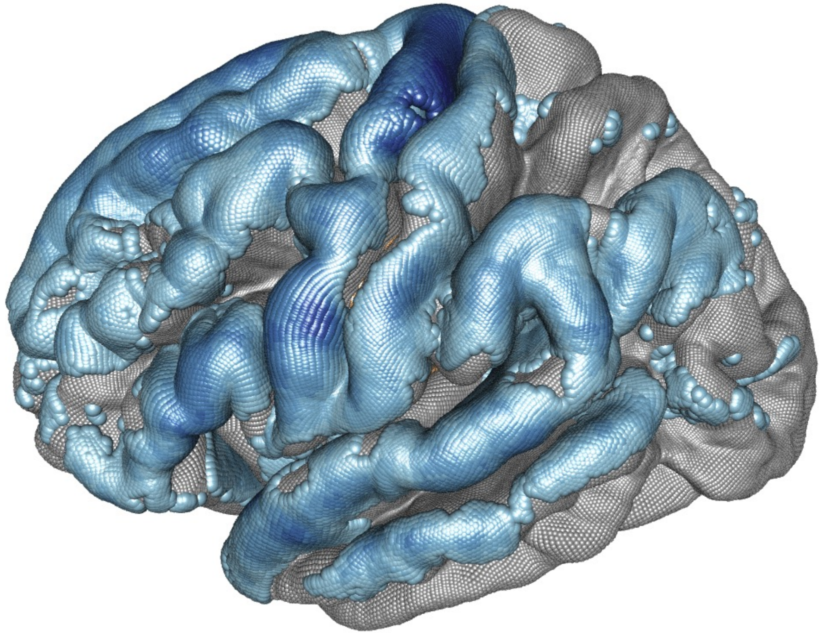
Parsimonious model for mass-univariate vertex-wise analysis Couvy-Duchesne, et al. J. of Medical Imaging, (2022)

Thank you

To all participants and data collection teams – UKB application 12505

Algorithmes, modèles et méthodes pour les images et les signaux du cerveau humain (ARAMIS) Paris Brain Institute

Program for Complex Trait Genomics (PCTG) Institute for Molecular Bioscience, the University of Queensland



Github/baptisteCD/brainMapR (R-package for brain plots and gifs)
Couvy-Duchesne et al., Human Brain Mapping, 2020
Couvy-Duchesne et al., IEEE 17th ISBI, 2020
Couvy-Duchesne et al., SPIE Medical Imaging, 2021
Couvy-Duchesne et al., JMI, 2022
Furtjes et al,. Cortex, 2023