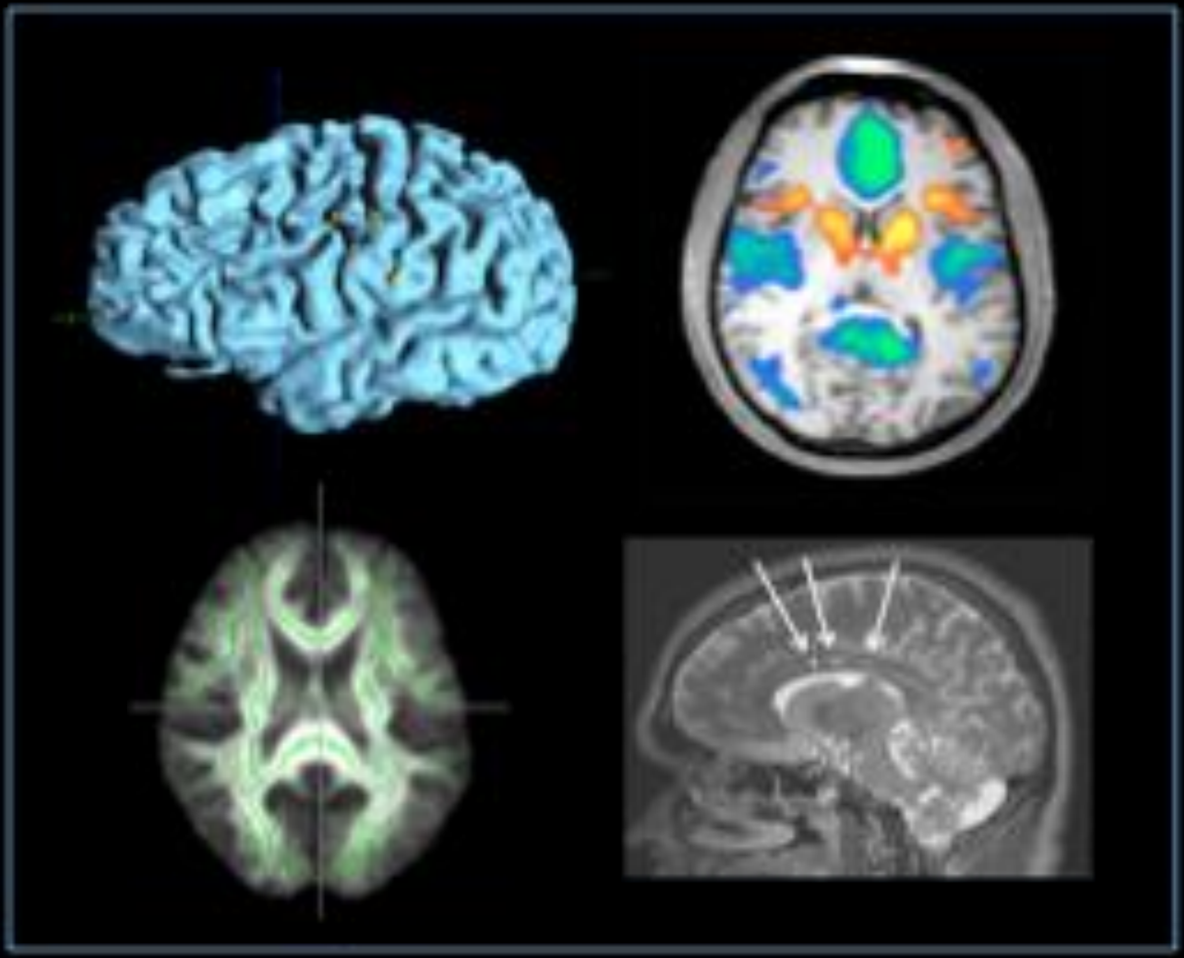
Understanding the inside of the black box: Optimizing approaches for the analysis of diffusion tensor imaging and cortical maps in TBI



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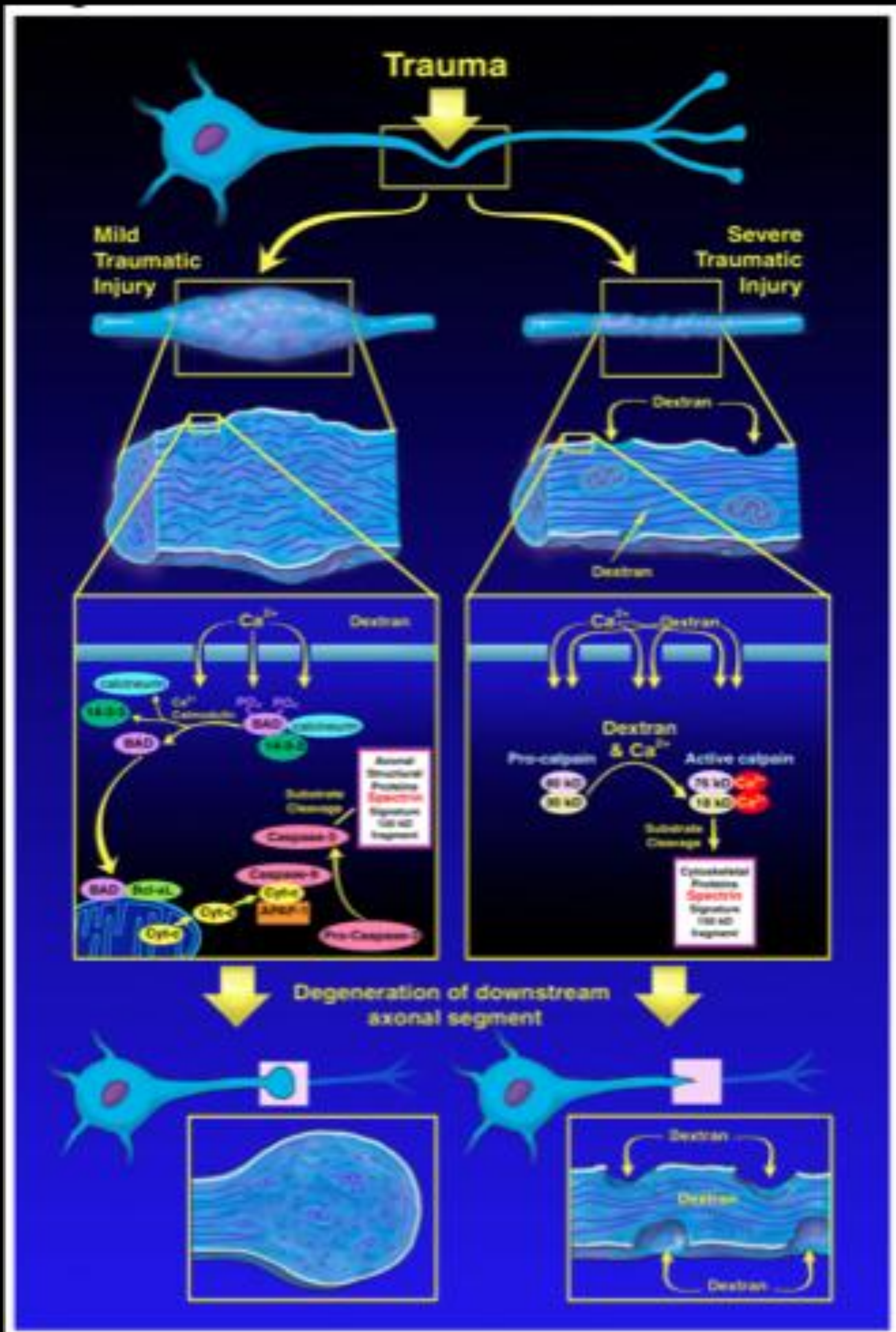
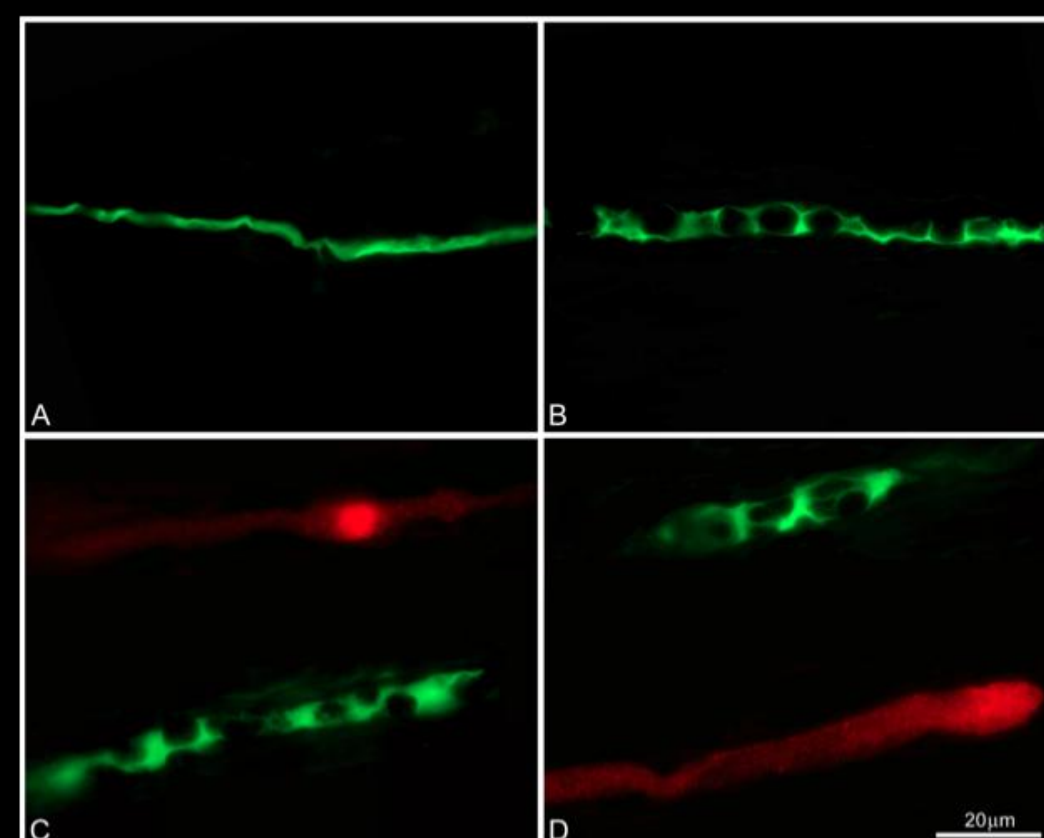
Neurological Surgery
University of Virginia Health System
Charlottesville, VA

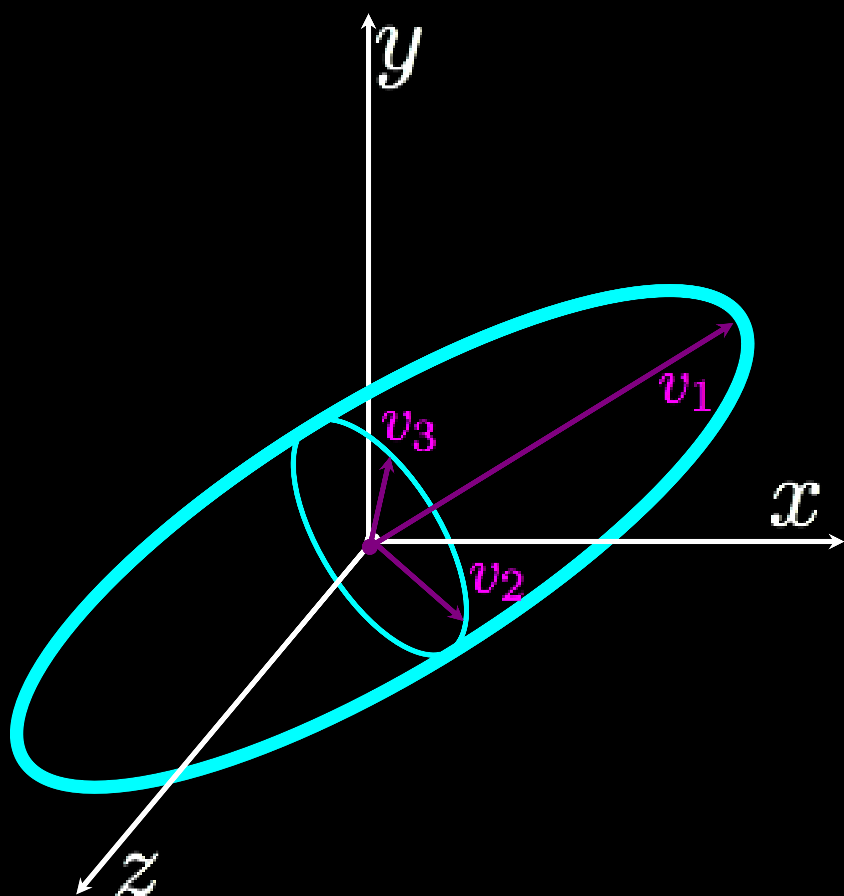
White matter changes in TBI

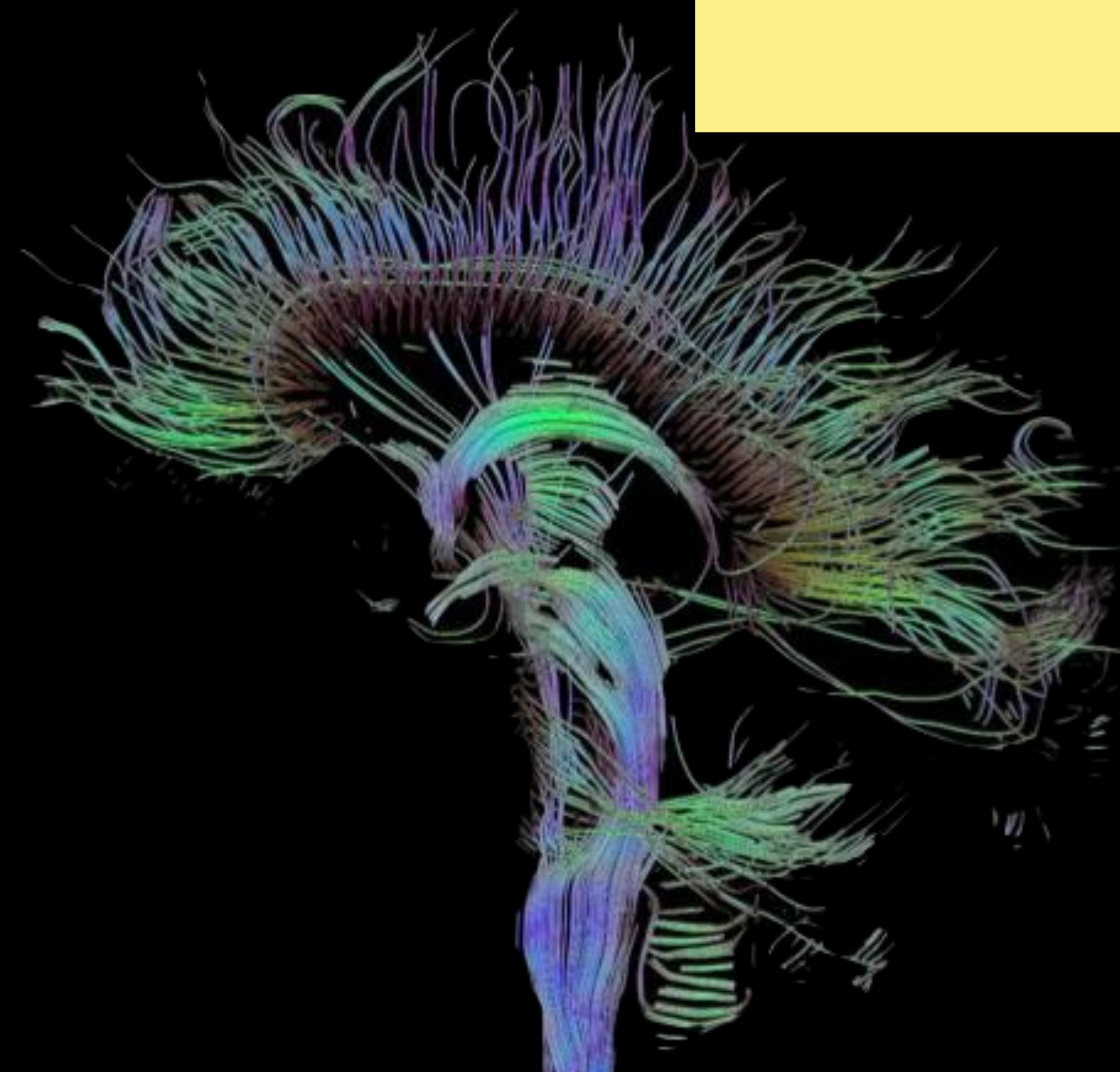




Diffusion tensor imaging

Need to put the eigenvalue decomposition equation here with the mean diffusivity and fractional isotropy definitions.





$$\mathrm{MD} = \bar{\lambda} = \frac{\lambda_1 + \lambda_2 + \lambda_3}{3}$$

$$\mathrm{FA} = \sqrt{\frac{3}{2}\frac{(\lambda_1 - \bar{\lambda})^2 + (\lambda_2 - \bar{\lambda})^2 + (\lambda_3 - \bar{\lambda})^2}{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$

DTI analysis possibilities

Manual ROIs

N Engl J Med. 2011 Jun 2;364(22):2091-100.

Detection of blast-related traumatic brain injury in U.S. military personnel.

Mac Donald CL, Johnson AM, Cooper D, Nelson EC, Werner NJ, Shimony JS, Snyder AZ, Raichle ME, Witherow JR, Fang R, Flaherty SF, Brody DL.

Automated ROIs

Neuroimage. 2011 Jan;54 Suppl 1:S21-9. Epub 2010 Sep 17.

Evidence of disrupted functional connectivity in the brain after combat-related blast injury.

Sponheim SR, McGuire KA, Kang SS, Davenport ND, Aviyente S, Bernat EM, Lim KO.

Tractography & Voxel-based analysis

J Neurotrauma. 2010 Apr;27(4):683-94.

Diffusion tensor imaging of mild to moderate blast-related traumatic brain injury and its sequelae.

Levin HS, Wilde E, Troyanskaya M, Petersen NJ, Scheibel R, Newsome M, Radaideh M, Wu T, Yallampalli R, Chu Z, Li X.

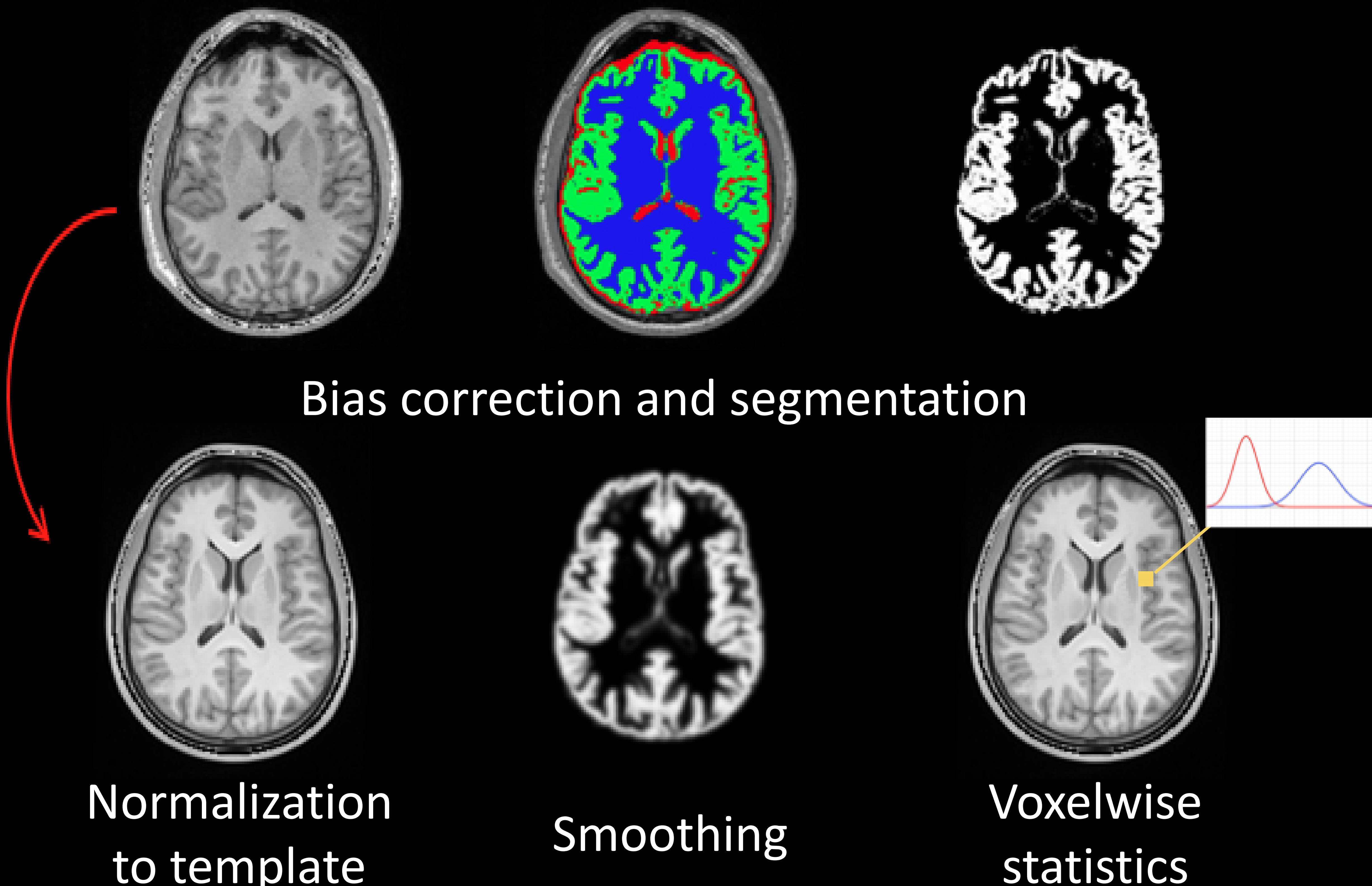
Tract-based spatial statistics

Brain. 2011 Feb;134(Pt 2):449-63. Epub 2010 Dec 29.

White matter damage and cognitive impairment after traumatic brain injury.

Kinnunen KM, Greenwood R, Powell JH, Leech R, Hawkins PC, Bonnelle V, Patel MC, Counsell SJ, Sharp DJ.

Voxel-based morphometry



I. C. Wright, et al. A voxel-based method for the statistical analysis of gray and white matter density applied to schizophrenia, NeuroImage. 2(4):244-252, December 1995.
J. Ashburner and K. Friston. “Voxel-based morphometry---the methods. NeuroImage, 11(6 Pt 1):805-21, June 2000.
F.L. Bookstein. "Voxel-based morphometry" should not be used with imperfectly registered images. Neuroimage, 14(6):1454-62, December 2001.
C. Davatzikos. Why voxel-based morphometric analysis should be used with great caution when characterizing group differences. NeuroImage, 23:17-20., 2004.

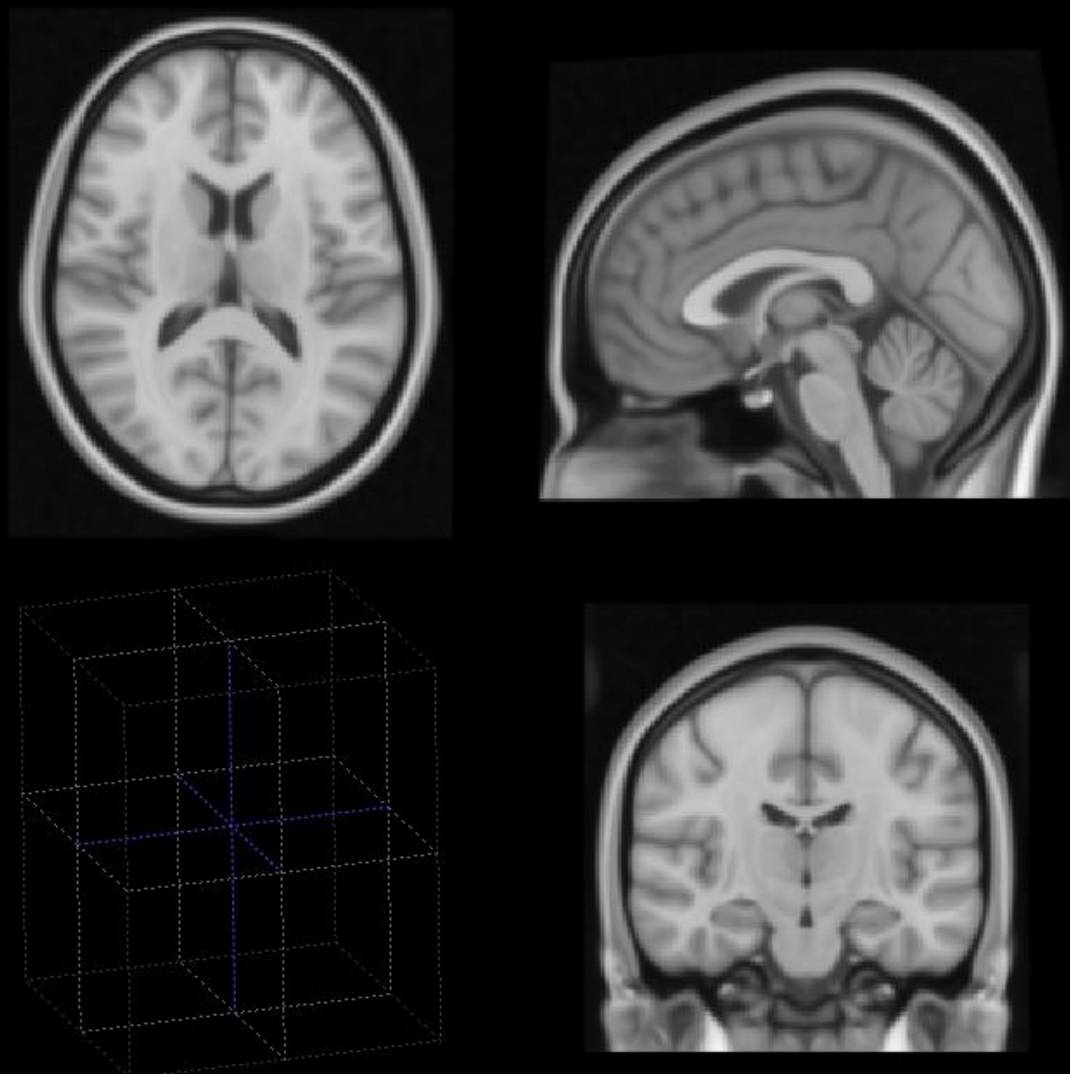
The Black Box

So which approach is the right one?

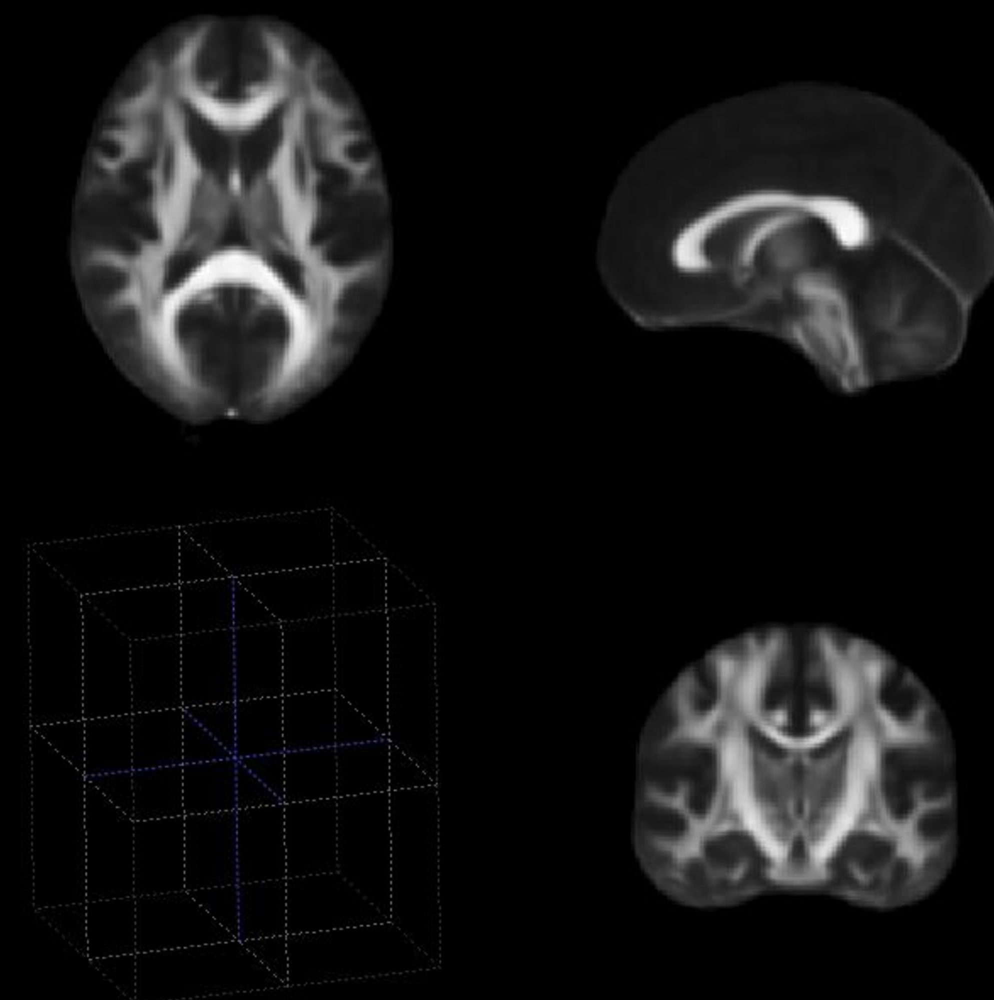
What about specific processing choices?
What statistical test do we use?
How much post-normalization smoothing do we use?

What registration package do I use, specifically,
what transformation model do I use and
what similarity metric do I use?
Also, does it matter the template choice?

Commonly used templates

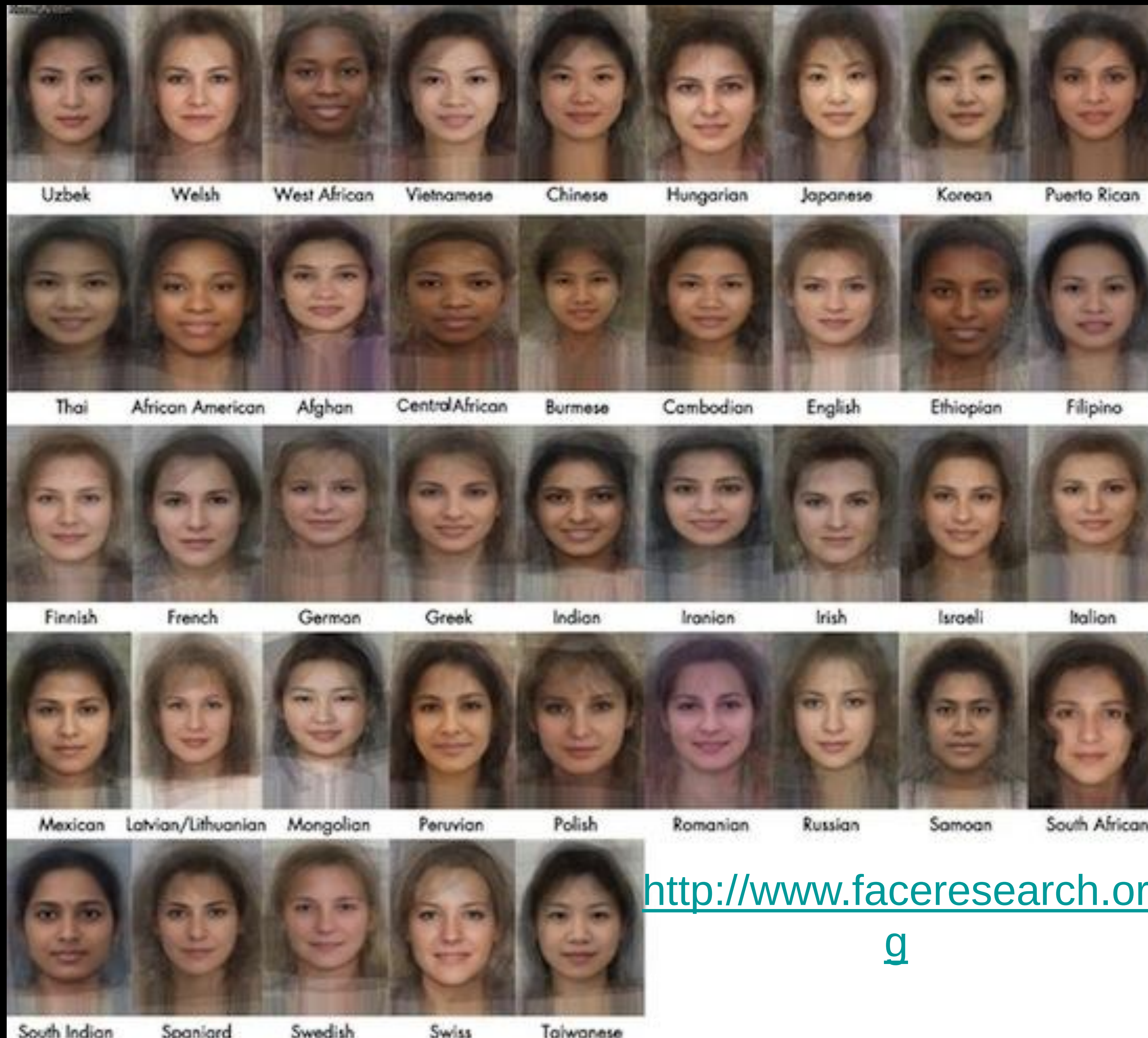


MNI152



FMRIB58

Templates: faces as motivation

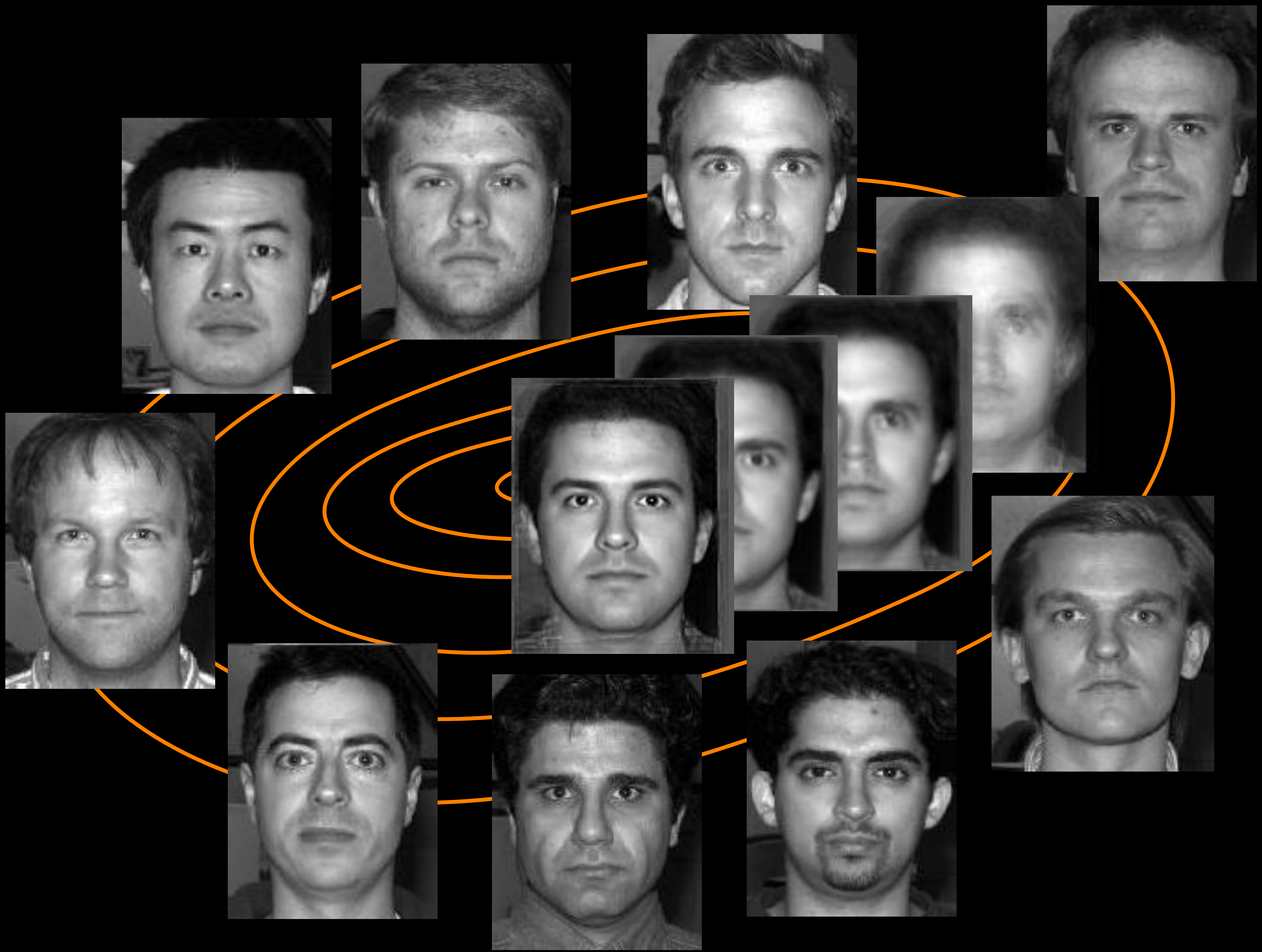


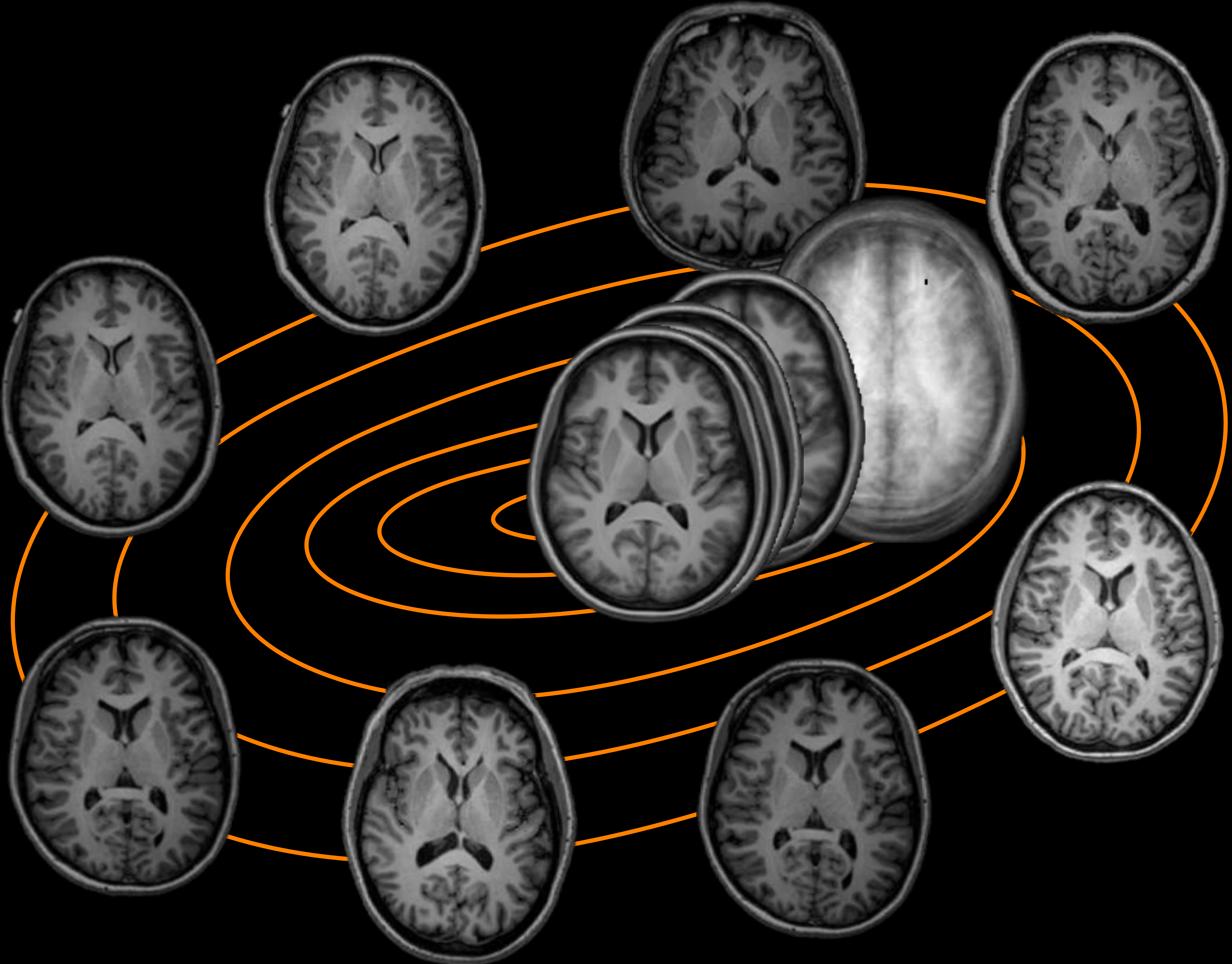
http://www.faceresearch.org

Psychol Sci. 2006 Sep;17(9):799-806.

Prototypes are attractive because they are easy on the mind.

Winkielman P, Halberstadt J, Fazendeiro T, Catty S.
University of California, San Diego, CA 92093-0109, USA. pwinkiel@ucsd.edu





Neuroimage. 2010 Feb 1;49(3):2457-66. Epub 2009 Oct 8.

The optimal template effect in hippocampus studies of diseased populations.

Avants BB, Yushkevich P, Pluta J, Minkoff D, Korczykowski M, Detre J, Gee JC.
Department of Radiology, University of Pennsylvania, Philadelphia, PA 19104, USA. avants@grasp.cis.upenn.edu

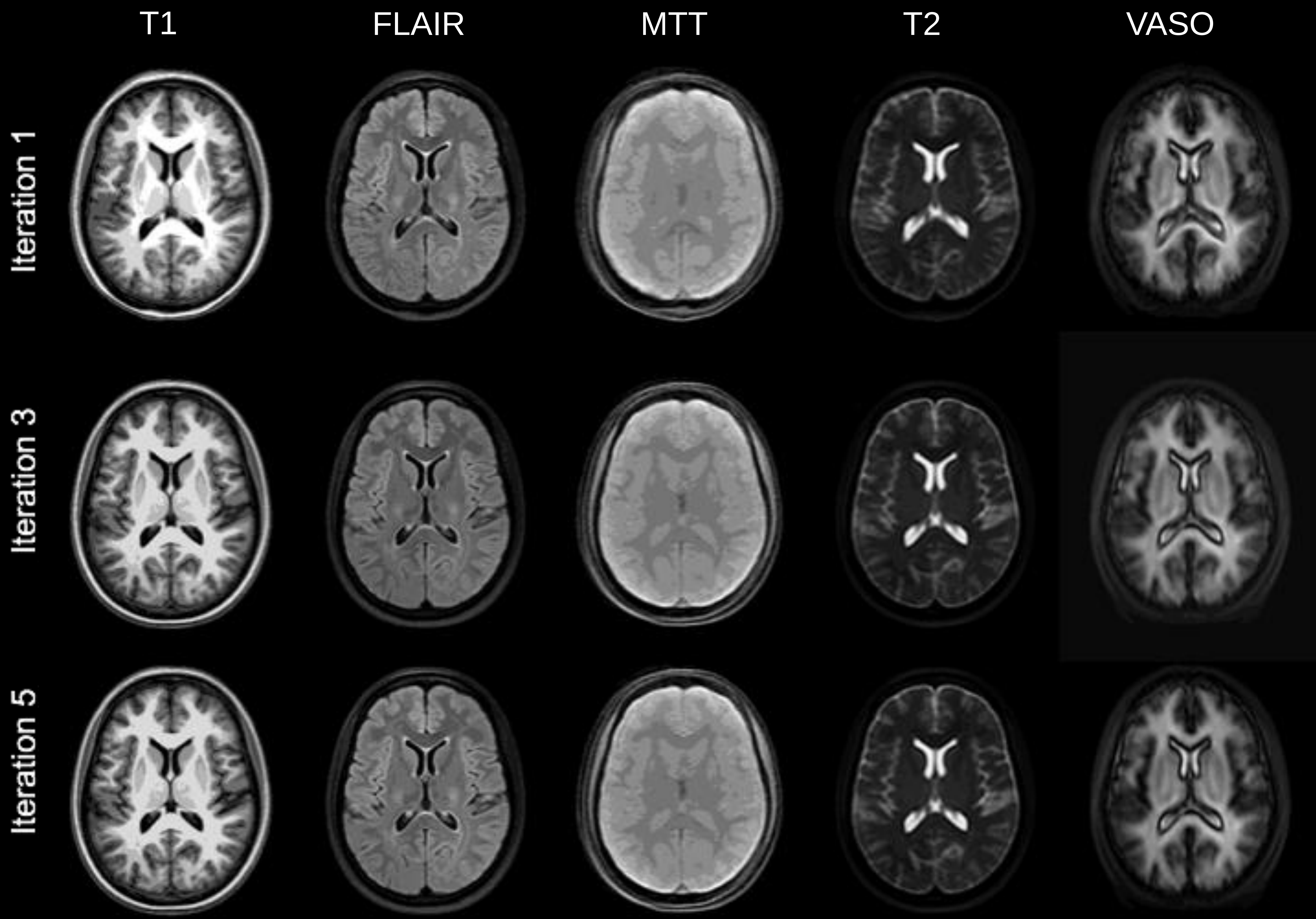
gender?

Neuroimage. 2011 Feb 14;54(4):2854-66. Epub 2010 Nov 20.

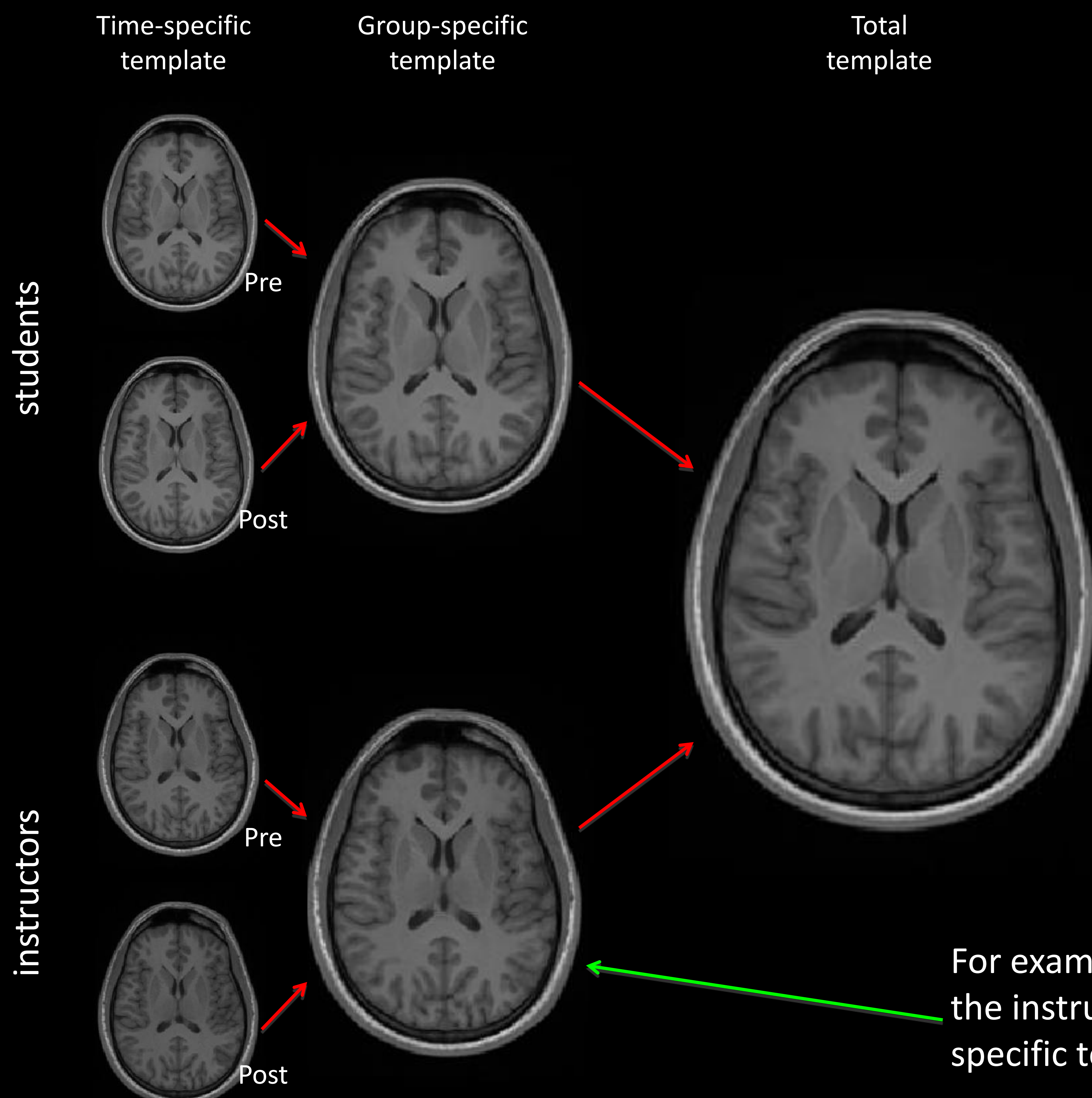
Multi-parametric neuroimaging reproducibility: a 3-T resource study.

Landman BA, Huang AJ, Gifford A, Vikram DS, Lim IA, Farrell JA, Bogovic JA, Hua J, Chen M, Jarso S, Smith SA, Joel S, Mori S, Pekar JJ, Barker PB, Prince JL, van Zijl PC.
Department of Electrical Engineering, Vanderbilt University, Nashville, TN 37235-1679, USA. bennett.landman@vanderbilt.edu

Multivariate template construction



Template construction for population studies

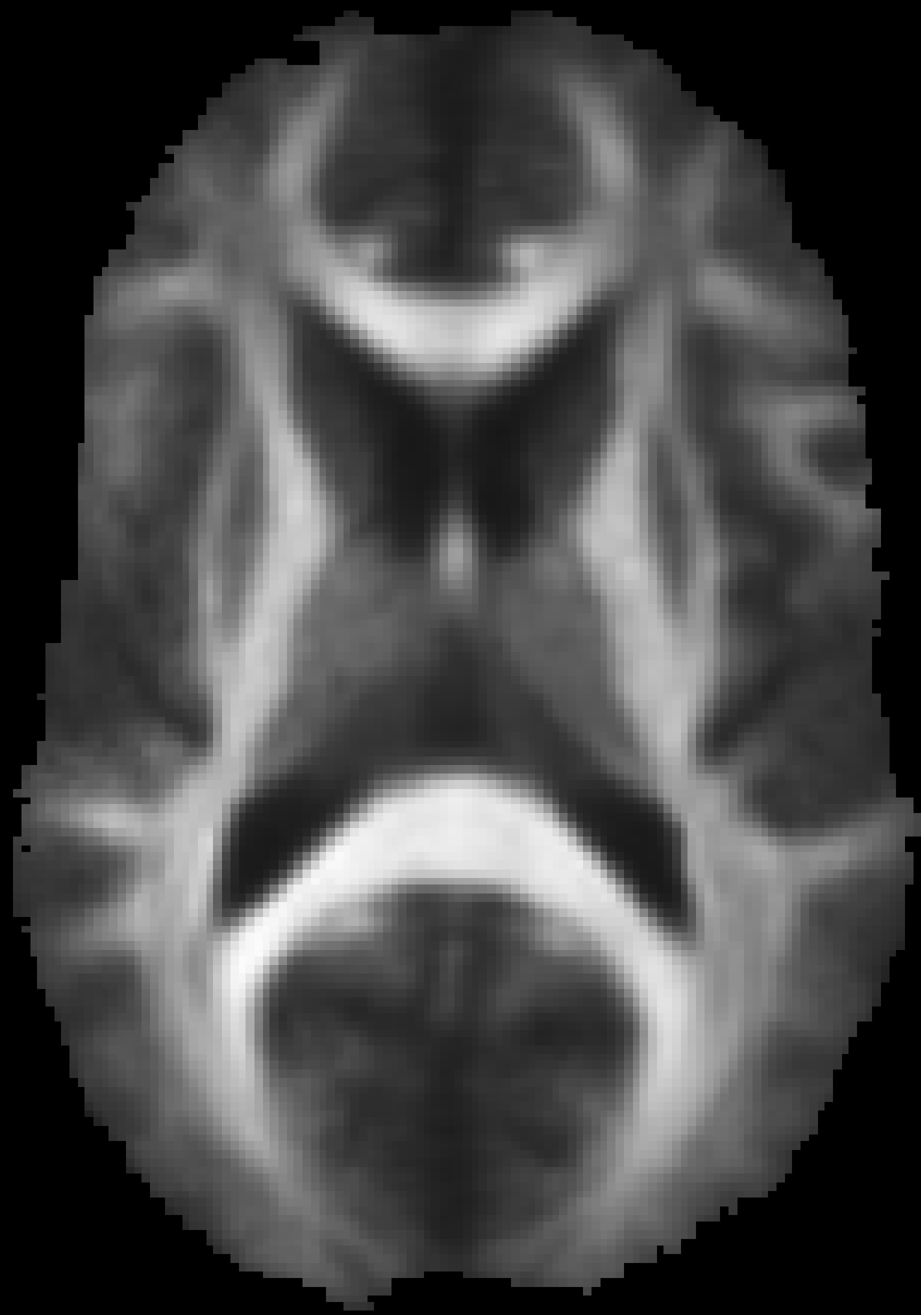


This template construction process gives us a standard coordinate system for any within-group or cross-group comparisons.

To test students vs. instructors, we use the total template.

For example, to test pre vs. post in the instructors, we use the group-specific template.

More robust approach to FA normalization



TBSS

via T1 template

Registration considerations

rank	LPBA40	μ (SD)	IBSR18	μ (SD)	CUMC12	μ (SD)	MGH10	μ (SD)
1	ART	.82 (.35)	SPM_D	.83 (.27)	SPM_D	.76 (.24)	SyN	.77 (.37)
	SyN	.60 (.38)	SyN	.72 (.51)	SyN	.74 (.51)	ART	.72 (.45)
	FNIRT	.49 (.66)	IRTK	.67 (.53)	IRTK	.74 (.50)	IRTK	.61 (.51)
	JRD-fluid	.49 (.66)	ART	.60 (.70)	ART	.60 (.70)		
2	IRTK	.43 (.63)	JRD-fluid	.30 (.82)			SPM_D	.27 (.23)
	D.Demons	.13 (.82)					D.Demons	.27 (.69)
	SPM_US	.11 (.83)					JRD-fluid	.24 (.66)
							ROMEO	.06 (.63)
3	ROMEO	.08 (.73)	FNIRT	.16 (.82)	D.Demons	.20 (.84)		
	SPM_D	.07 (.29)	D.Demons	.05 (.84)	FNIRT	.18 (.81)		
					JRD-fluid	.17 (.81)		

One of the most significant findings of this study is that the relative performances of the registration methods under comparison appear to be little affected by the choice of subject population, labeling protocol, and type of overlap measure...ART, SyN, IRTK, and SPM's DARTEL Toolbox gave the best results according to overlap and distance measures, with ART and SyN delivering the most consistently high accuracy across subjects and label sets.

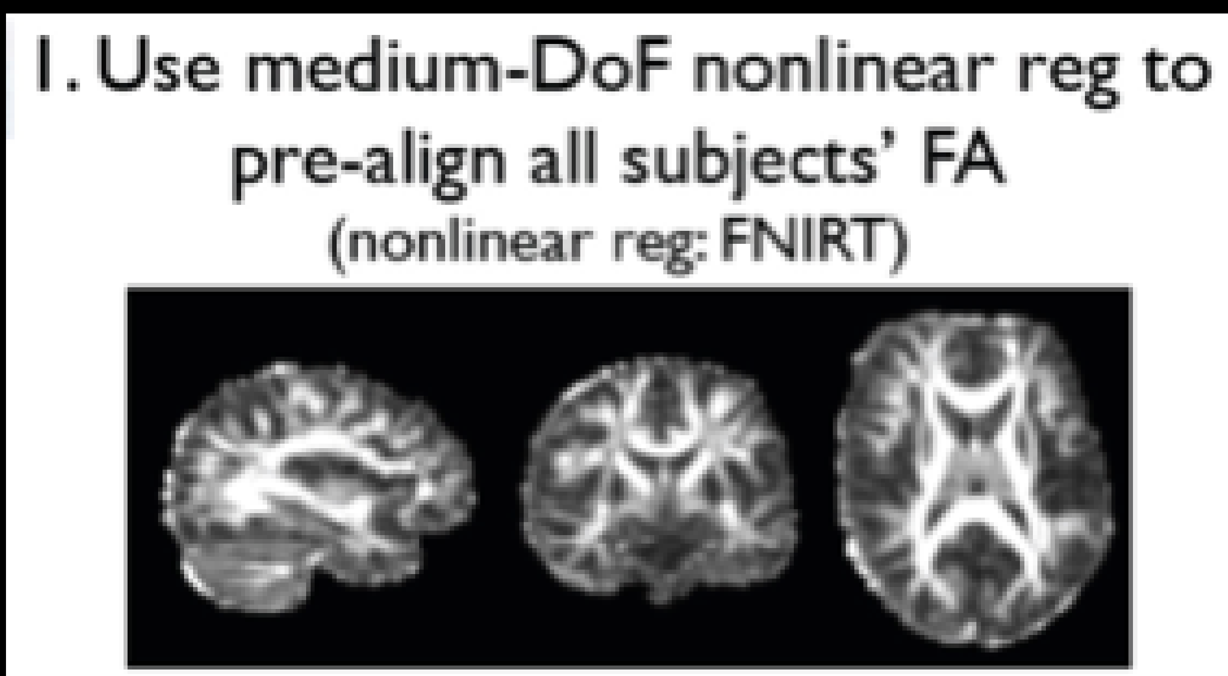
Neuroimage. 2009 Jul 1;46(3):786-802. Epub 2009 Jan 13.

Evaluation of 14 nonlinear deformation algorithms applied to human brain MRI registration.

Klein A, Andersson J, Ardekani BA, Ashburner J, Avants B, Chiang MC, Christensen GE, Collins DL, Gee J, Hellier P, Song JH, Jenkinson M, Lepage C, Rueckert D, Thompson P, Vercauteren T, Woods RP, Mann JJ, Parsey RV.

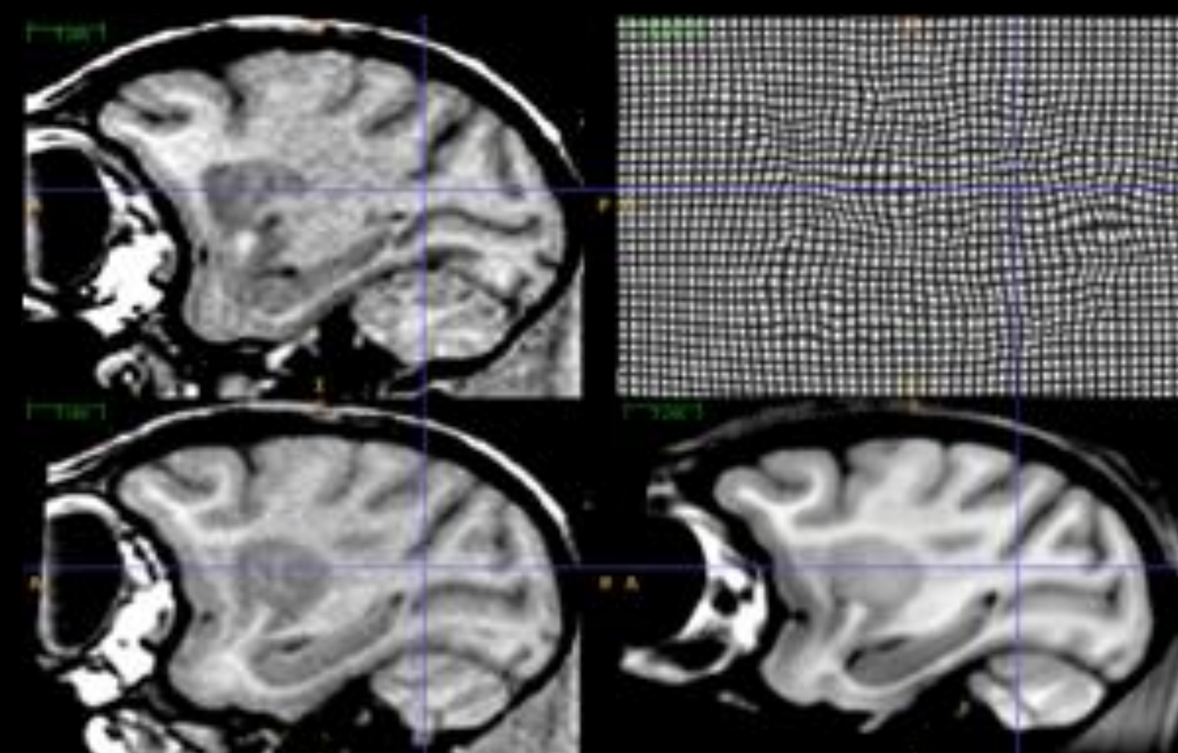
Not all transforms are created equal

FSL nonrigid image registration tool (FNIRT)

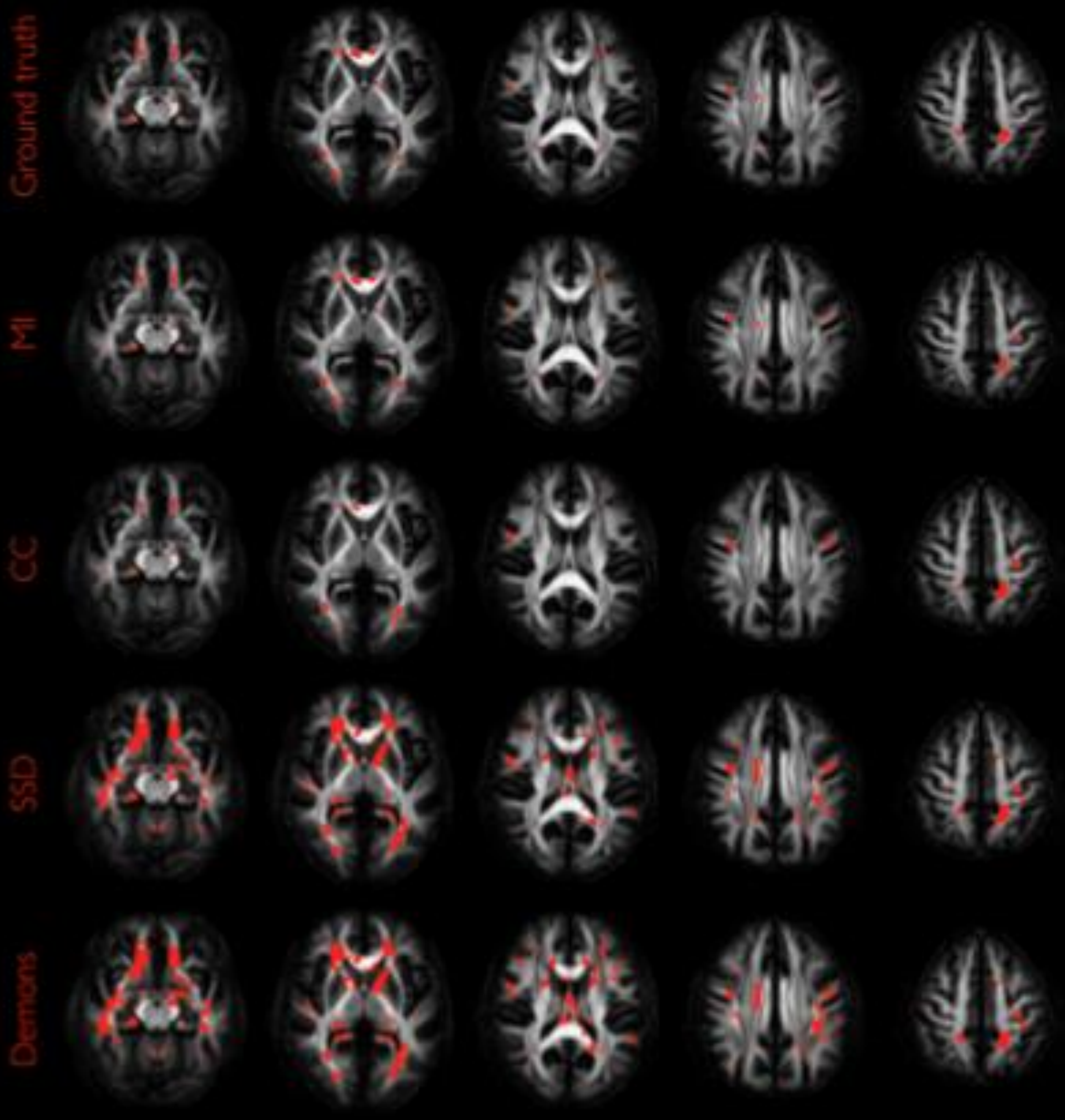


vs.

Symmetric Normalization (high resolution diffeomorphisms)

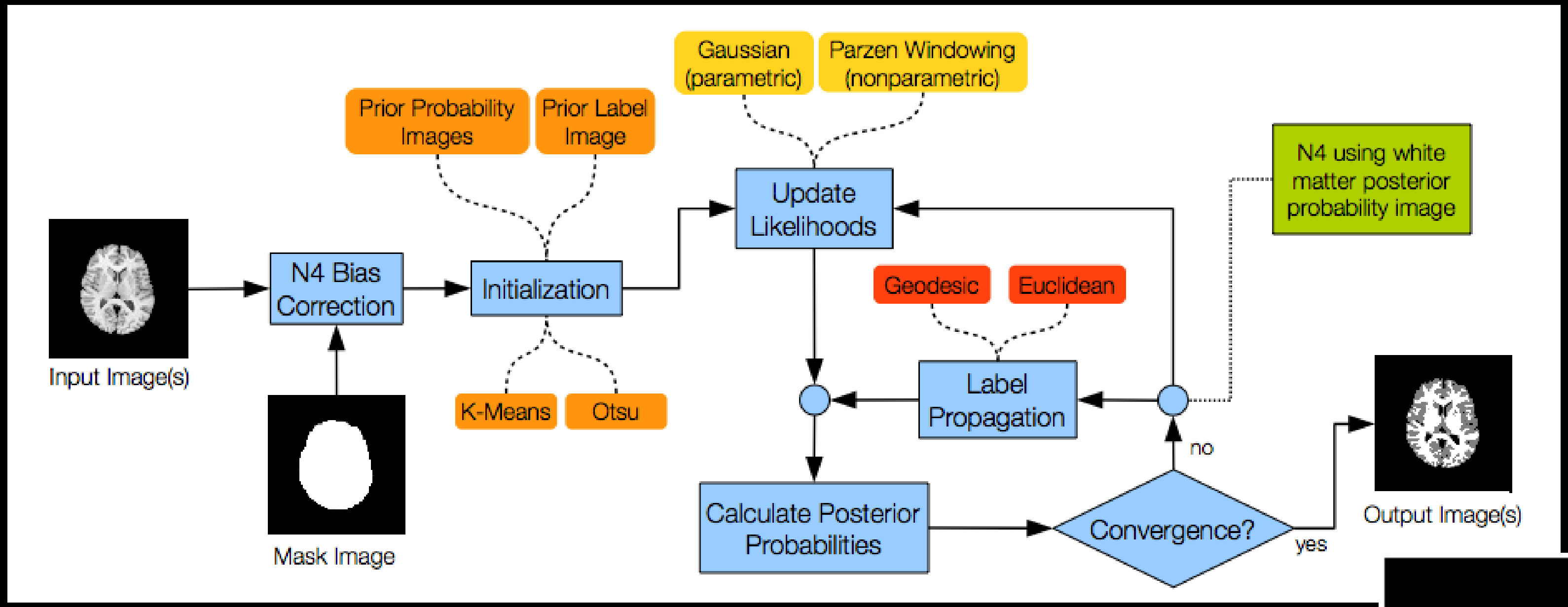


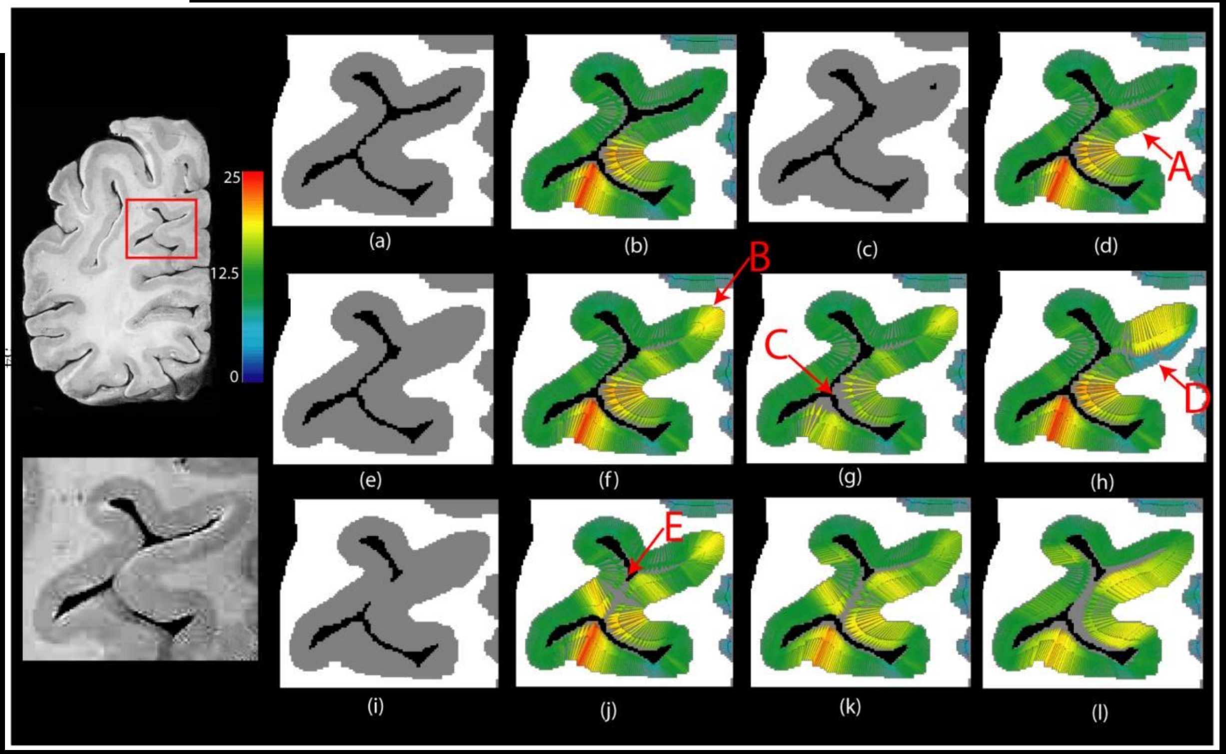
Similarity metric considerations



N. J. Tustison, B. B. Avants, P. A. Cook, J. Kim, J. Whyte, J. C. Gee, J. R. Stone. Circularity in voxel-based analysis, Human Brain Mapping, *submitted*.

Cortical thickness maps





IEEE Trans Med Imaging. 2010 Jun;29(6):1310-20. Epub 2010 Apr 8.

N4ITK: improved N3 bias correction.

Tustison NJ, Avants BB, Cook PA, Zheng Y, Egan A, Yushkevich PA, Gee JC.
Department of Radiology, University of Pennsylvania, Philadelphia, PA 19140, USA. ntustison@wustl.edu

Neuroinformatics. 2011 Dec;9(4):381-400.

An Open Source Multivariate Framework for n-Tissue Segmentation with Evaluation on Public Data.

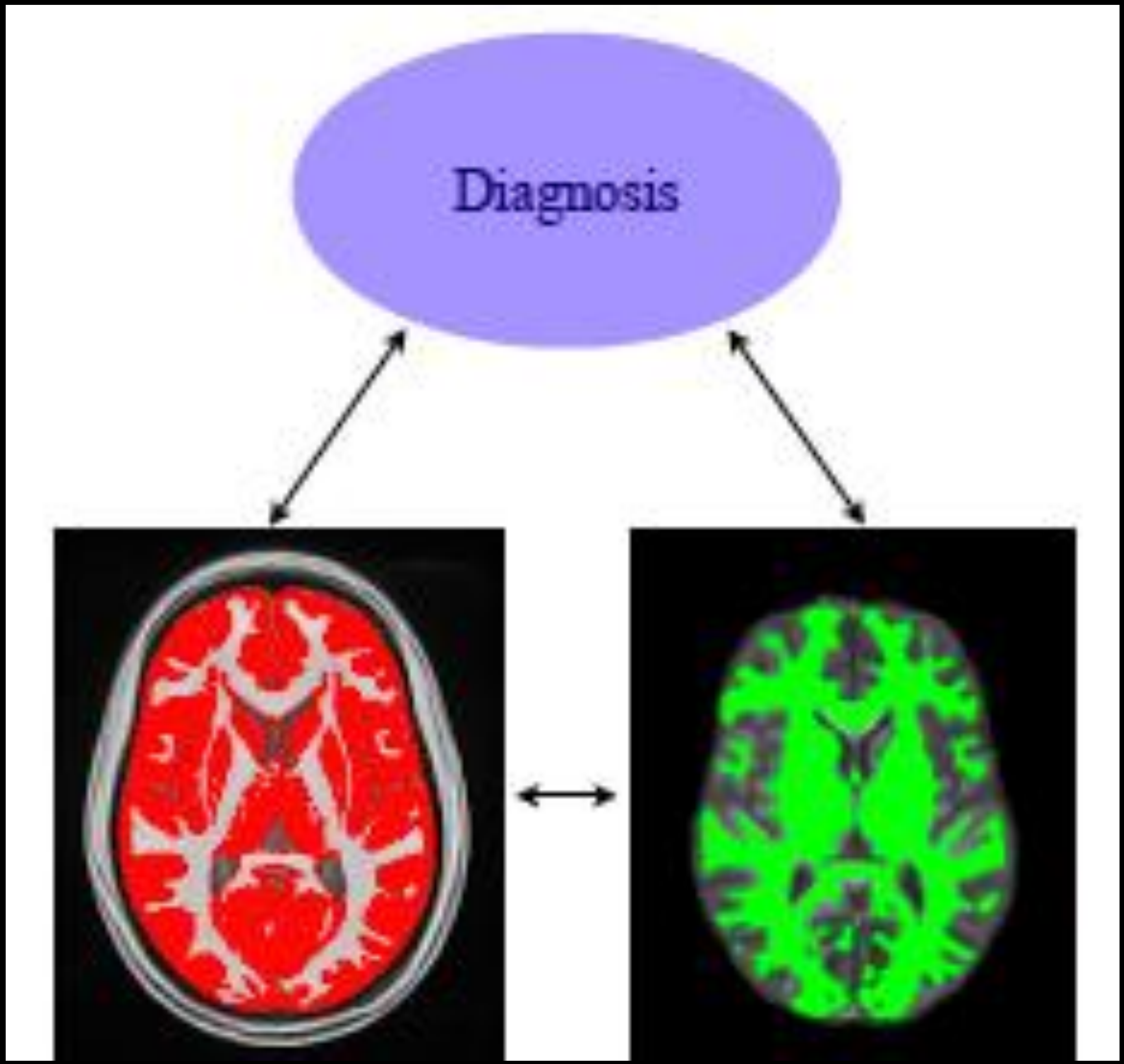
Avants BB, Tustison NJ, Wu J, Cook PA, Gee JC.
Penn Image Computing and Science Laboratory, University of Pennsylvania, 3600 Market Street, Suite 370, Philadelphia, PA, 19104, USA, stnava@gmail.com.

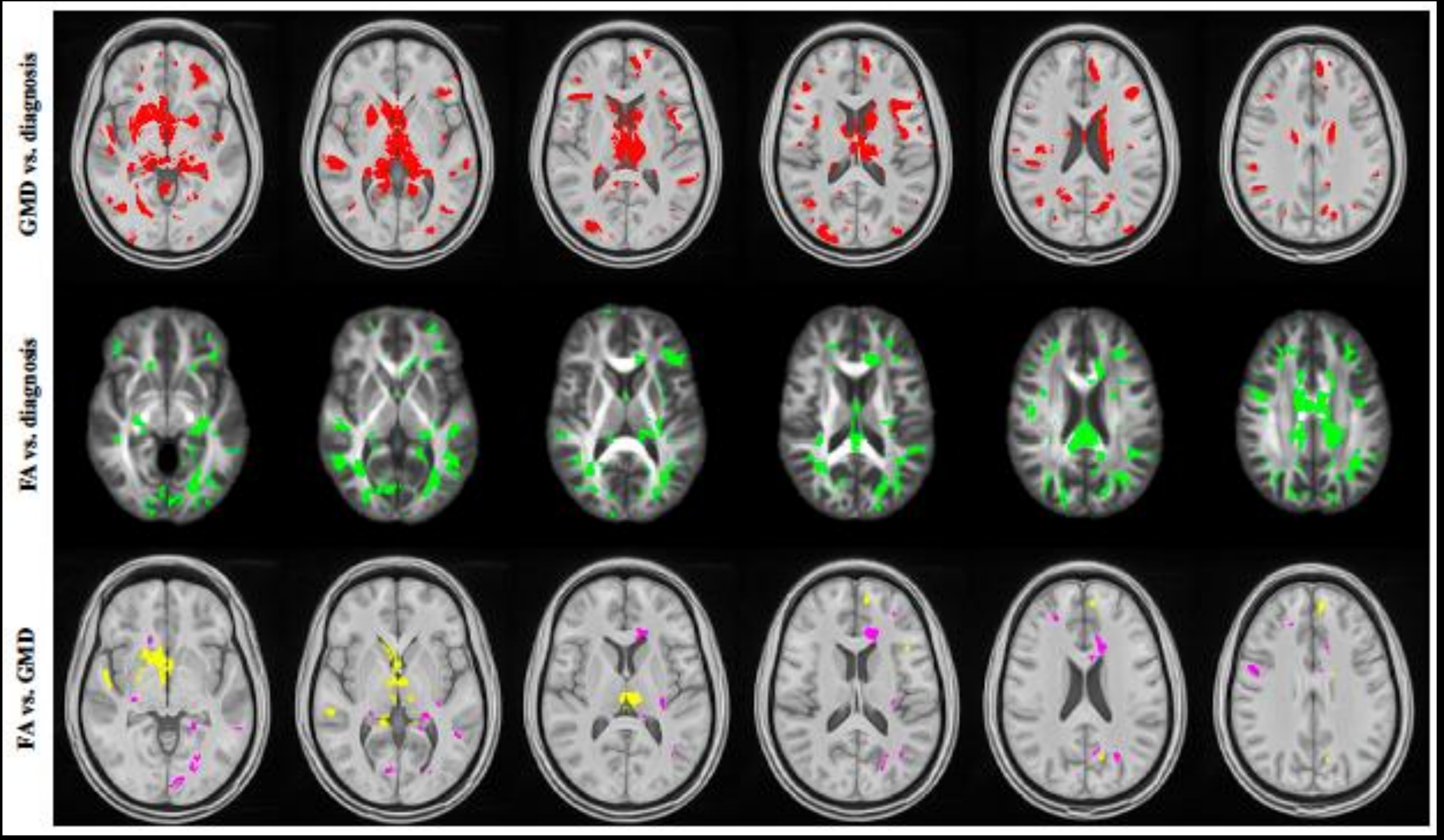
Neuroimage. 2009 Apr 15;45(3):867-79. Epub 2008 Dec 25.

Registration based cortical thickness measurement.

Das SR, Avants BB, Grossman M, Gee JC.
Department of Radiology, University of Pennsylvania School of Medicine, Philadelphia, PA, USA. sudas@seas.upenn.edu

Sparse Canonical Correlation Analysis (SCCA)




GMD vs. diagnosis
FA vs. diagnosis
FA vs. GMD

Thank you!

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