



THE STRENGTHS AND CHALLENGES OF USING FUNCTIONAL MRI AND OTHER PROCEDURES IN NEUROSURGICAL BRAIN MAPPING

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LEARNING OBJECTIVES

- Understand the common indications for brain mapping during neurosurgical workup
- Specific procedural aspects of fMRI
- Illustrate the strengths and weaknesses of using functional MRI/DTI with neurosurgical patients with real-world examples
- Workflow of clinical MRI mapping
- Compare clinical vs. research uses of fMRI/DTI

*Why a neuropsychologist is ideal for
presurgical mapping*

SOME DEFINITIONS OF TERMS USED WITHIN THE SCOPE OF THIS WORKSHOP:

1. **Clinical functional MRI (fMRI):** noninvasive brain MRI procedure used to determine *location* of certain functions; resting state fMRI (rsfMRI) is currently not widely available
2. **DTI:** diffusion tensor imaging: MRI sequence sensitive to white matter. A post-processing procedure, **tractography**, is used to isolate specific white matter tracts
3. **Lesion:** generic term to describe the presence of a brain abnormality that can be seen on a brain scan (versus e.g., “non-lesional epilepsy”)
4. **Structural vs. Functional Neuroimaging:** structural images visualize brain structures while functional scans determine metabolism, brain activity, blood flow, etc. **fMRI** is a **functional** scan, **DTI** is a **structural** scan
5. **Mass effect:** the presence of a mass-occupying lesion creates pressure on other regions, distorts surrounding brain tissue; mass effects can cause life-threatening herniation
6. **Lateralization vs localization:** lateralizing of a cognitive function, such as left hemisphere language dominance vs. localization of language function within a specific area of the left hemisphere
7. **Cognition:** in the context of this topic, the term cognition will include motor functioning and vision; is mostly restricted to functions critical for basic functioning (ADLs).

SOME DEFINITIONS OF TERMS USED WITHIN THE SCOPE OF THIS WORKSHOP (cont):

1. **“Eloquent” Cortex:** a term used by many neurosurgeons typically for cortex involved in language, motor, vision (and memory) areas that will cause catastrophic post-surgical deficits. May mean different things by users.
2. **BOLD imaging:** **“Blood oxygenation level dependent** imaging is the foundation for the fMRI signal. It allows fast scanning of the entire brain and is sensitive to the amount of oxygenation present (mechanism discussed in talk).
3. **Post-processing:** The procedures done on “raw” MR images that provide the brain mapping. Different programs are used to produce the **statistical maps** for fMRI and DTI.
4. **GBM:** Glioblastoma multiforme; a high-grade glioma brain tumor. While complete “cure” is difficult to obtain, surgery helps with mass effect (which can be deadly) and extend survival time.
5. **AVM and Cavernous malformation (“Cav mal”):** Arteriovenous malformation and cav mal are vascular lesions that can cause brain bleeds and can be treated with various techniques, including surgery. Due to aberrant blood flow, they interfere with the MRI signal used for both fMRI and DTI.
6. **PACS system:** PACS is “Picture Archiving and Communication System” a generic term for the imaging programs that allow review of imaging data. For end-users, the programs also show the radiology report with the data and allow annotation to aid communication with end-users. There are many different programs used in hospitals.

Examples of patients referred for brain mapping prior to brain neurosurgery

63 y.o. right-handed woman with a left temporal lobe glioblastoma multiforme

Language
Comprehension

49 y.o. right-handed man with a left frontal cavernous malformation and seizures

Language
Expression

51 y.o. right-handed man with a large right posterior frontal lobe tumor near motor area

Mass effect; visualize
motor cortex,
language confirmation

68 y.o. left-handed woman with a right frontal lobe low grade tumor

Language
lateralization
/localization

23 y.o. right-handed man with left temporal lobe intractable seizures (epilepsy)

Language
Comprehension

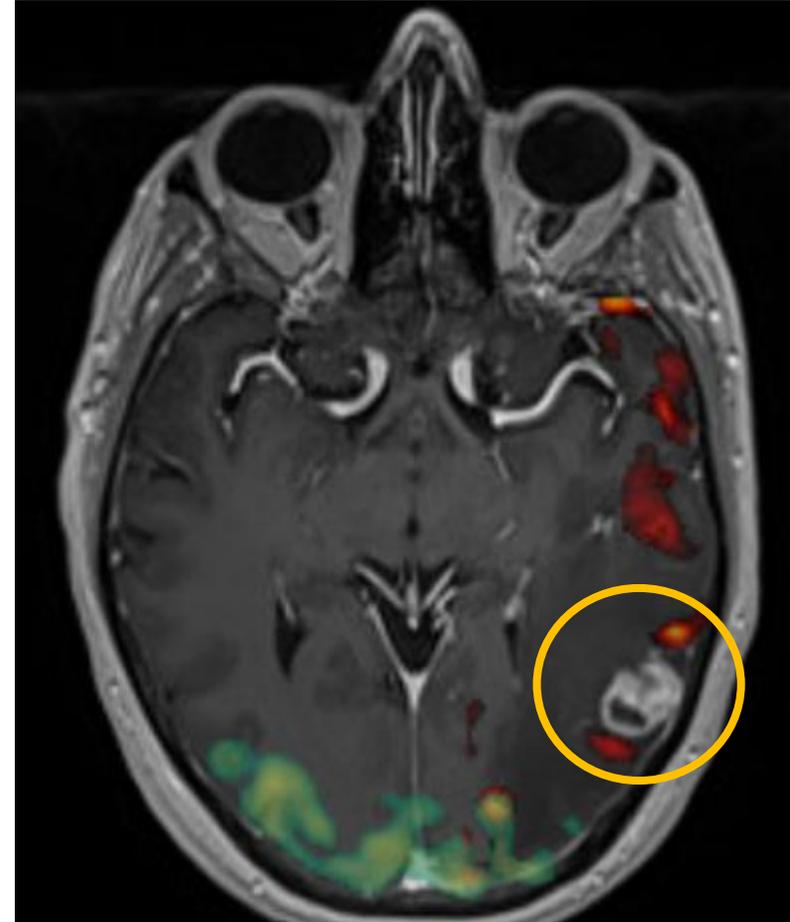
Clinical Neuropsychologists as part of the Neurosurgery Planning Team

- Neuropsychological assessment of cognition
 - In epilepsy, correlation of cognitive/emotional findings with other indications of seizure focus
 - In tumors, vascular lesions, objective indication of level of cognition prior to surgery; indications for post-surgical rehab, etc.
- Pre-surgical brain mapping using functional MRI and DTI vs. MRI technologist/Neuroradiology method
- Bedside mapping for epilepsy patients
- Intraoperative monitoring and mapping
Wada

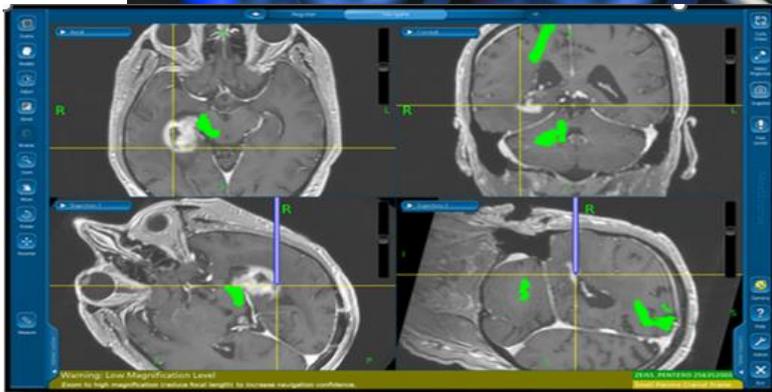
CPT code 70555 is used to describe a functional magnetic resonance imaging (fMRI) of the brain, which is performed by a physician or psychologist. Code 96020 is professional code Neurofunctional mapping

Specific Indications for Clinical fMRI and DTI

- NOT diagnostic but localization: Where in the brain are “eloquent” areas that should not be resected?
- Trajectory: how best to approach a lesion through intact tissue?
- Visualize areas that might be easily identified typically but are distorted due to mass effects
- Neuronavigation



Neuronavigation: Using pre-operative data in the OR



“Wand”
Neuronavigation Tool

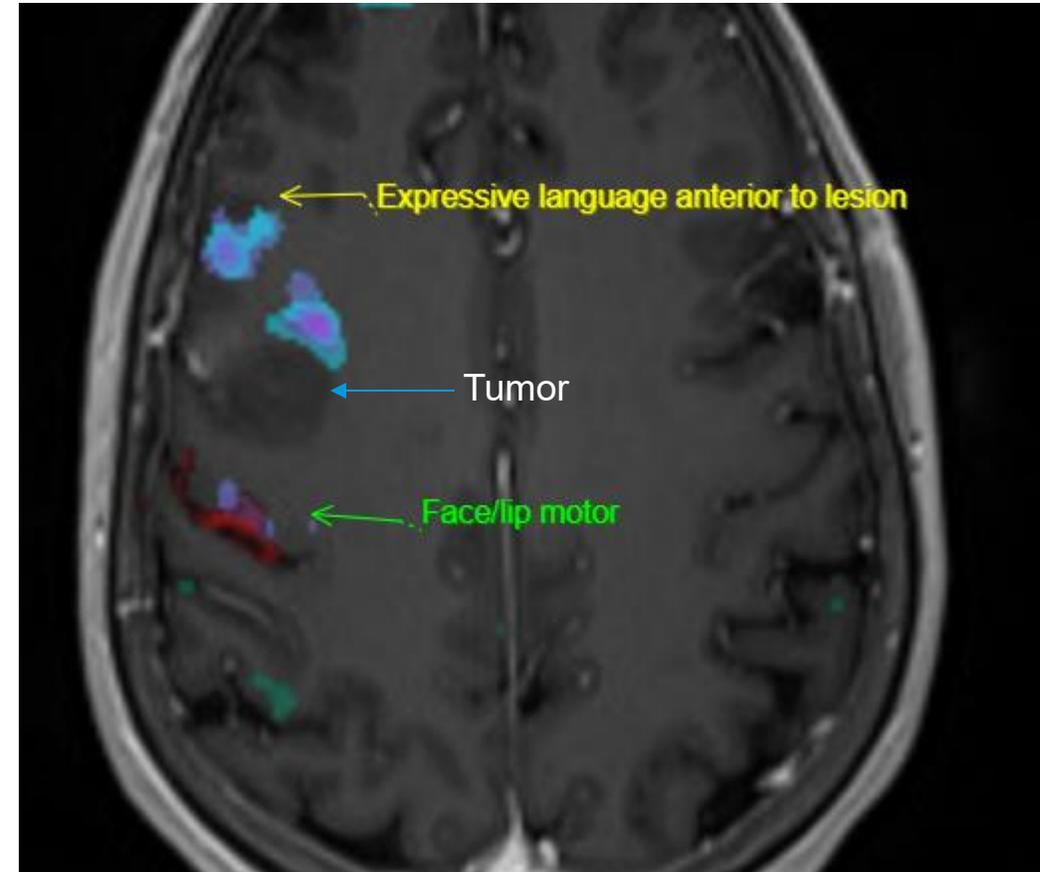
Brain mapping via fMRI and DTI help presurgically with determining the “risk-benefit” tradeoff

For Brain Tumor patients, there is worry about the “Onco-Functional Balance”: balance between performing as **complete a surgery** as possible without causing **a major cognitive deficit**.

For Epilepsy patients, the wish is for better seizure control because repeated seizures can lead to severe cognitive difficulties or death.

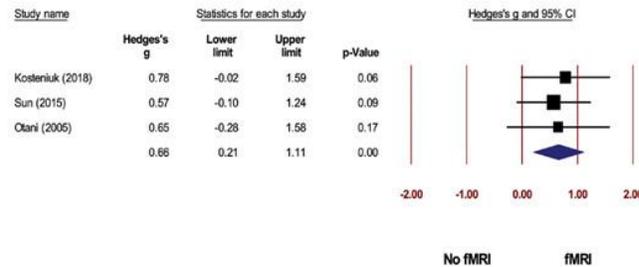
HOW DOES FMRI/DTI AND OTHER PRESURGICAL BRAIN MAPPING TECHNIQUES AFFECT PRESURGICAL CLINICAL DECISION MAKING?

- Presurgical fMRI/DTI and other brain mapping procedures are presented in **clinical case conference** within the context of other information.
- In some (most) brain tumor cases, the timeline for discussing presurgical information is limited due to the nature of care. Information is communicated through the PACS (right), in person, and/or at conference



Evidence for using presurgical mapping to improve post-surgical outcome

Can Preoperative Mapping with Functional MRI Reduce Morbidity in Brain Tumor Resection? A Systematic Review and Meta-Analysis of 68 Observational Studies



Forest plot for random-effects meta-analyses with 95% CIs in patients undergoing brain tumor surgery with and without presurgical fMRI mapping by using Hedges *g* for pre- and postsurgical mean Karnofsky performance status score.

- In a systematic review and meta-analysis of 68 observational studies, postsurgical functional deterioration was less likely to occur when presurgical functional MRI (fMRI) mapping was performed (odds ratio, 0.25; $P < .001$).
- Patients with fMRI mapping had higher postsurgical Karnofsky performance status scores (Hedges $g = 0.66$; $P = .004$).
- Preoperative fMRI mapping for the resection of brain tumors resulted in a pooled adverse event rate (ER) of 11%, compared with an ER of 21% in patients who did not undergo fMRI mapping.



Luna L et al. Published Online: June 1, 2021
<https://doi.org/10.1148/radiol.2021204723>

Radiology

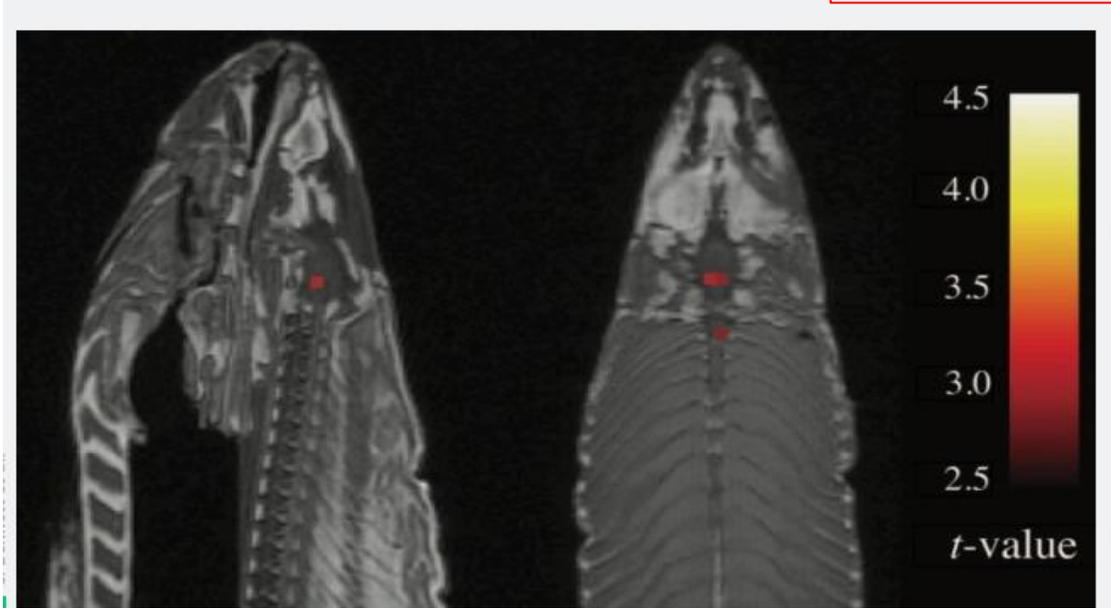
Preoperative FMRI associated with decreased mortality and morbidity in brain tumor patients



S. Vysotski^a, C. Madura^b, B. Swan^c, R. Holdsworth^a, Y. Lin^d, A. Munoz Del Rio^{a,e}, J. Wood^f, B. Kundu^g, A. Penwarden^h, J. Voss^a, T. Gallagherⁱ, V.A. Nair^a, A. Field^{j,k}, C. Garcia-Ramos^e, M.E. Meyerand^{k,l}, M. Baskaya^m, V. Prabhakaran^{n,*}, J.S. Kuo^{o,p}

Is there utility of fMRI/DTI

KNOW HOW YOUR DATA
ARE GENERATED!



Bennett, C. M., Miller, M. B., & Wolford, G. L. (2009). Neural correlates of interspecies perspective taking in the post-mortem Atlantic Salmon: an argument for multiple comparisons correction. *Neuroimage*, 47(Suppl 1), S125.

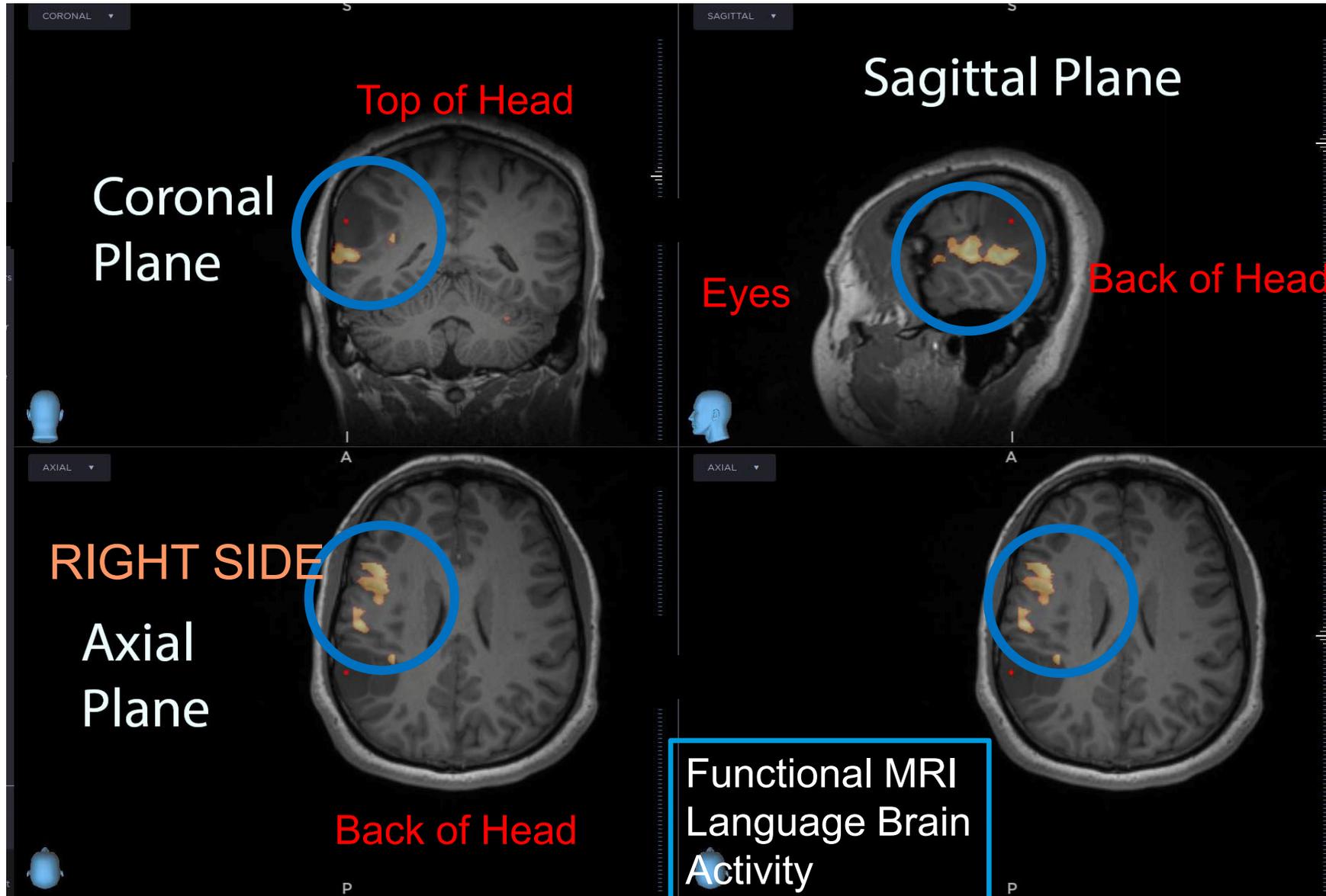
Organization for Human Brain Mapping



Committee on Best Practices 2025 (see Refs):

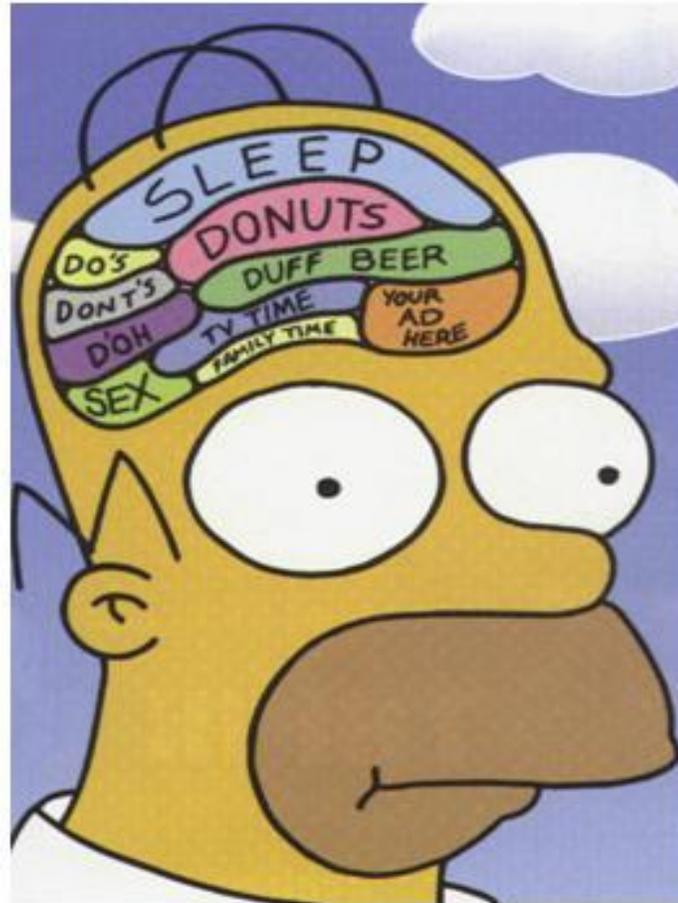
provides an in-depth, practical framework for presurgical clinical (language) fMRI assessments

MRI Brain Image Orientation



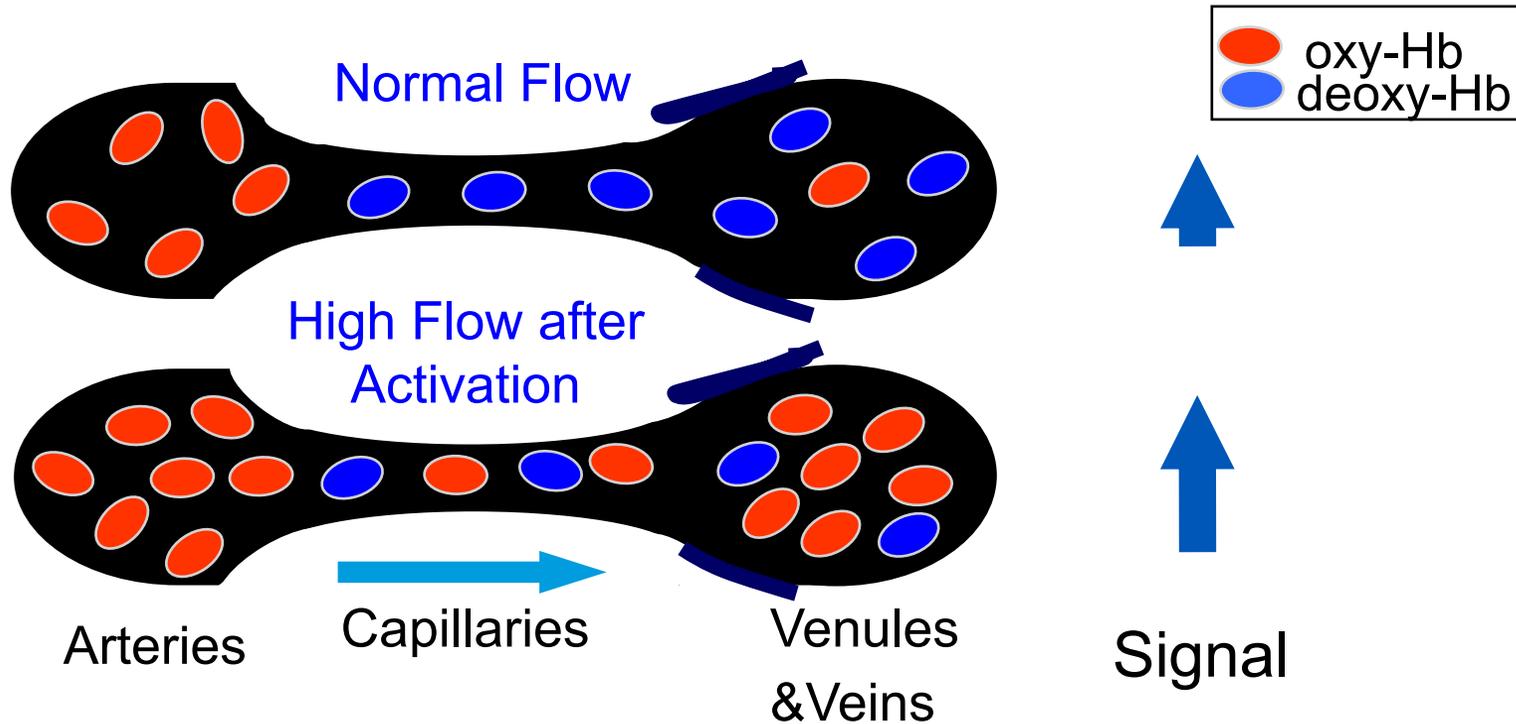


STRUCTURE

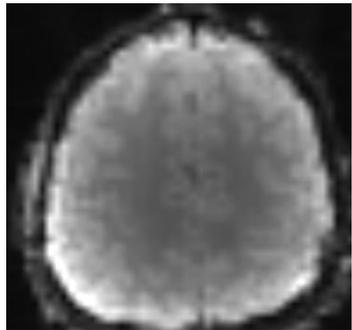


FUNCTION

The BOLD signal: Blood Oxygenation Level Dependent for fMRI



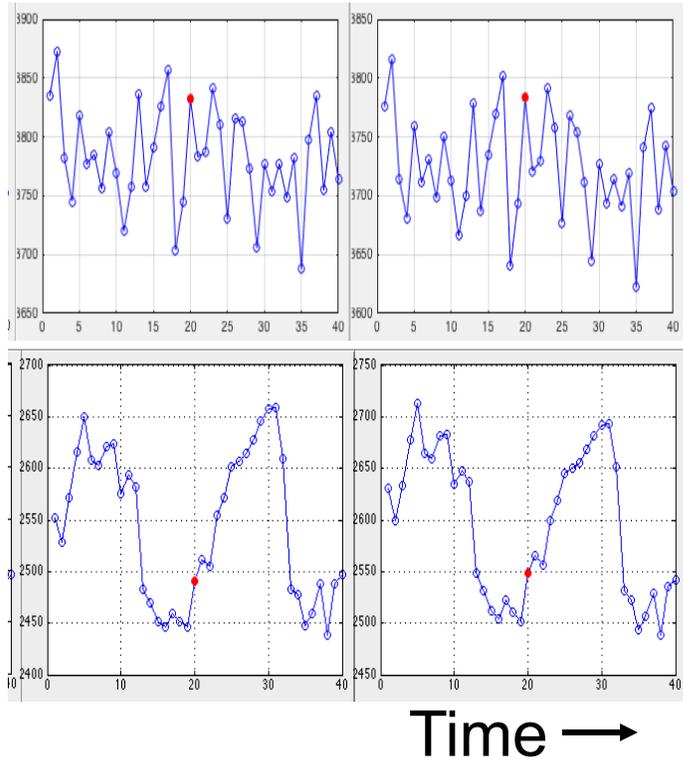
Adapted from
Dr. A. Saykin
(personal
correspondence)



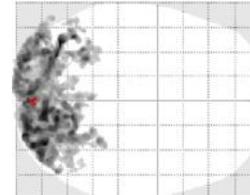
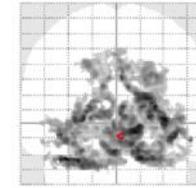
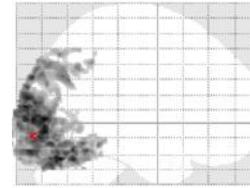
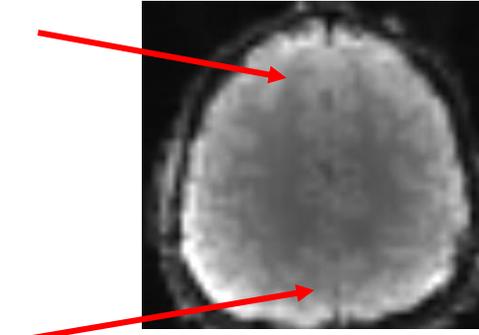
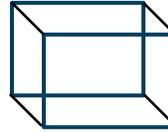
“T2*” MRI signal sensitive to paramagnetic changes related to the level of oxygenated blood because oxygen binds to iron-containing hemoglobin

THE BOLD SIGNAL TRANSLATED TO FMRI DATA

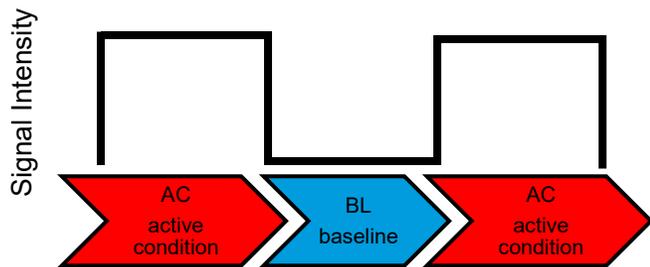
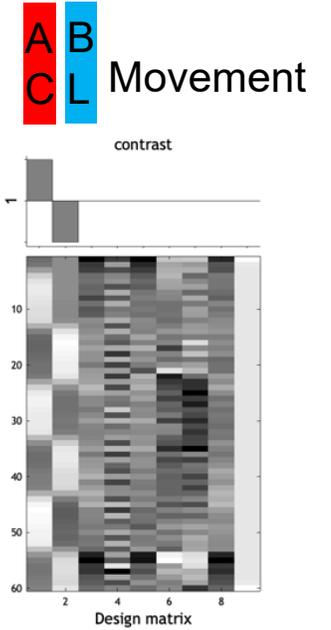
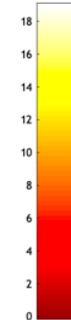
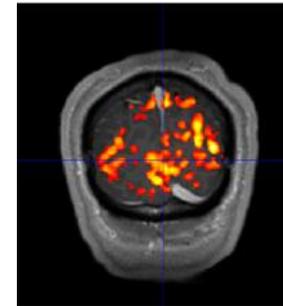
Signal Intensity ↑



Voxel: 3D Pixel
e.g., 3x3x3 mm³



SPM{T₅₀}



fMRI statistical question from a GLM model:
Where in the brain is there more activity in the active condition vs. baseline

CLINICAL NEUROPSYCHOLOGISTS ARE WELL-PREPARED FOR CLINICAL FMRI MAPPING

- Functional MRI is a *behavioral* test visualized through MRI
- Similar to other assessments of behavior, there are many constraints as to how information is collected.
- Patient-related issues need to be considered like anxiety, cognitive impairment, fatigue, lack of tolerance
- Neuropsychologists understand statistics

Clinical fMRI/tractography Workflow/procedure

Patients referred through a neurosurgeon or neurologist

- For the most part, there are no “diagnostic” clinical fMRIs (we don’t diagnose ADHD, etc)
- Scheduling can be challenging with high-grade tumors due to the immediacy of the cases

Prior to the procedure, chart review is required to understand the nature of the question and ascertain the adequacy of the patient’s ability to participate with the MRI

Assess the patient for level of functioning.

- Handedness for writing
- Language ability- naming, paraphasic errors? Ability to understand task demands
- Motor functioning
- Back pain, attention, other factors
- Education level

Just prior to the scan, the fMRI procedure is explained, and the patient is introduced to the fMRI tasks.

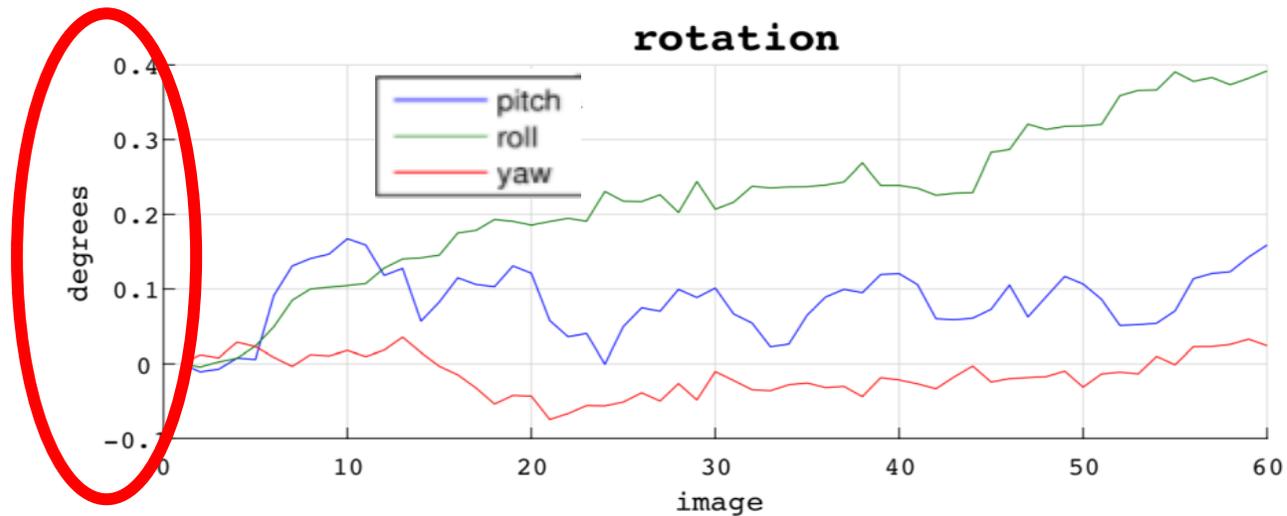
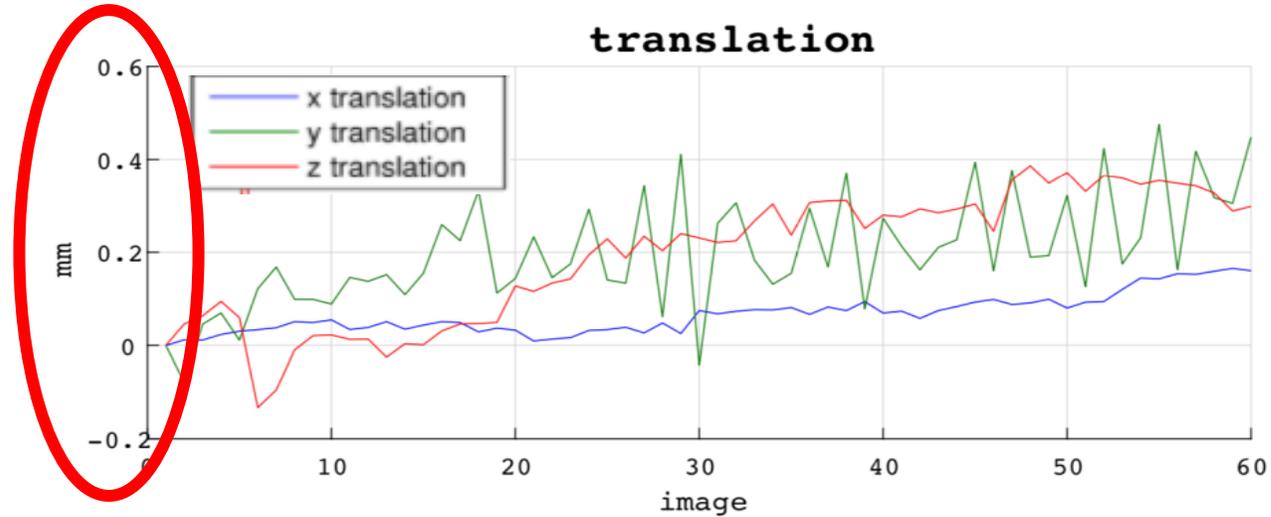
Clinical fMRI/tractography Workflow/procedure

- Clinical neuropsychology at its best: patients are often very upset, tearful, scared. This is combined with claustrophobia and pain and other problems make it crucial that good clinical rapport is established to get results.
- Patients are made comfortable in the MRI with great attention to minimizing movement.
- If at all possible, looking at the results of each scan as they are generated helps guide the workflow including:
 - How many tasks you might need to answer the question (e.g., in a left-handed patient with a right sided tumor, you may just need a few)
 - Are they moving? Did they fall asleep? Extra instructions or step/downs needed
- After the fMRI tasks, DTI and other “structural” scans are completed and then the final data can be analyzed.

CLINICAL FMRI PROTOCOLS: TASK DESIGN AND CHOICE

- Tasks must be *simple enough for impaired patients*
 - Step-down versions of language tasks
 - Simple directions
- Task must be representative of a critical cognitive function
 - Surgical Definition of Eloquent Cortex*
 - language: expressive, receptive, naming-conjunction of several tasks (e.g. auditory and reading comprehension)
 - motor: face/lip, hand, foot/toe (see Gordon et al. 2023 (Nature); excellent paper for update on the homunculus)
 - vision

CONSIDERATIONS FOR CLINICAL FMRI MAPPING: MOVEMENT



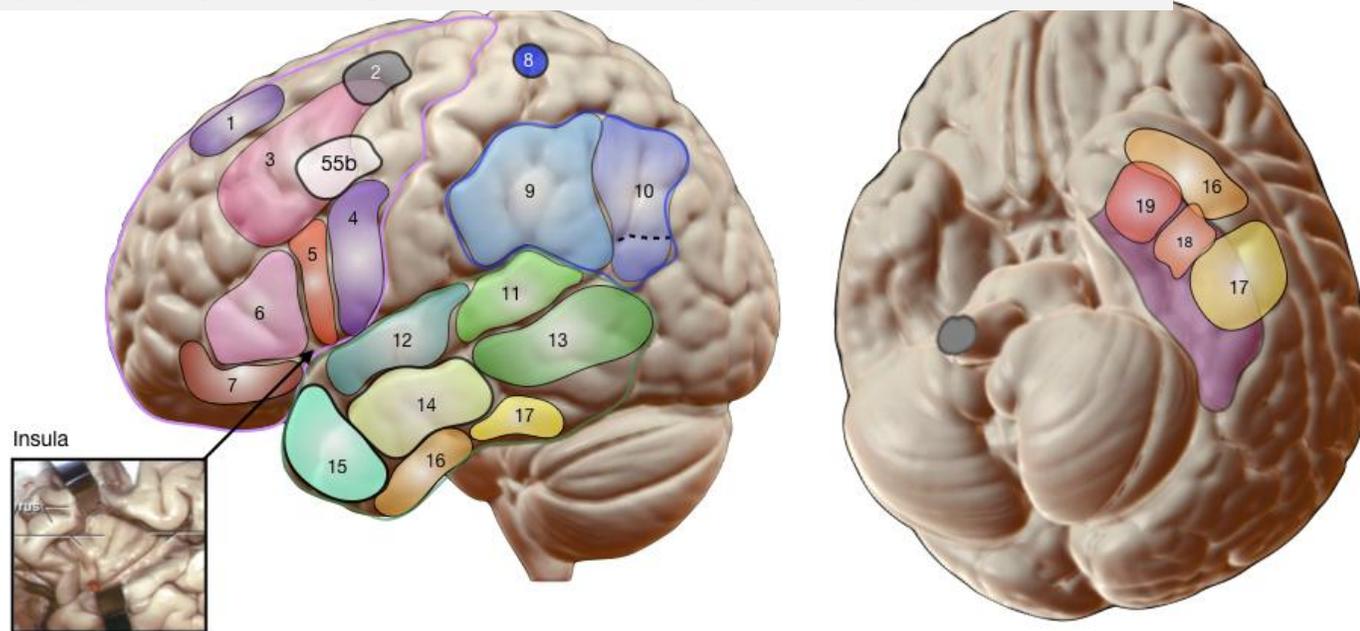
Head slightly pitching when moving lips; although tiny, it correlates with task and will introduce noise

Other considerations in language mapping

- Requiring a response during the task (usually via a button press)
 - Pros: Allows for assessment of participation- are they engage in the task? Are they performing well?
 - Cons: May activate additional brain areas involved in working memory, vigilance, especially if baseline is not well-balanced for task demand; also the decision-making process more complex processing and may be hard for cognitively impaired patients
- Scan Time
 - The longer the scan, the more robust signal
 - The longer the scan, the more likely movement will interfere, and/or the patient will want to stop
 - Tasks are often 4 minutes or less

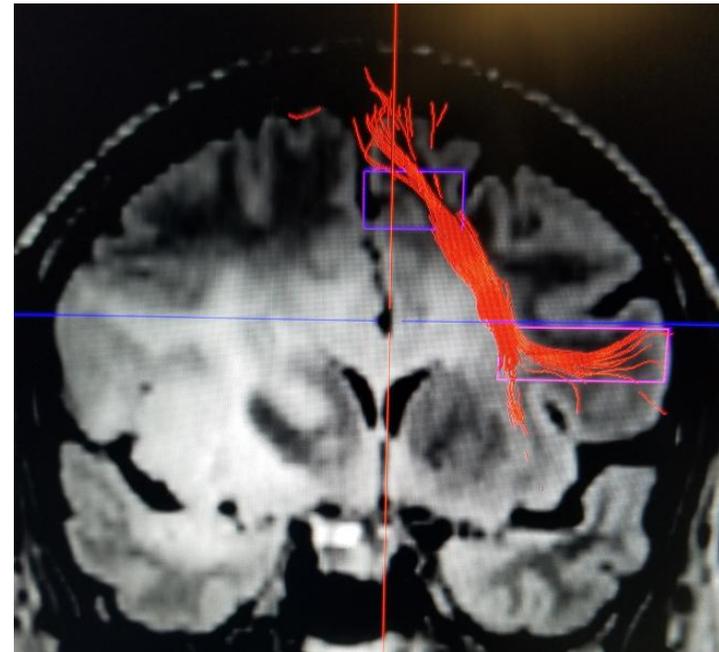
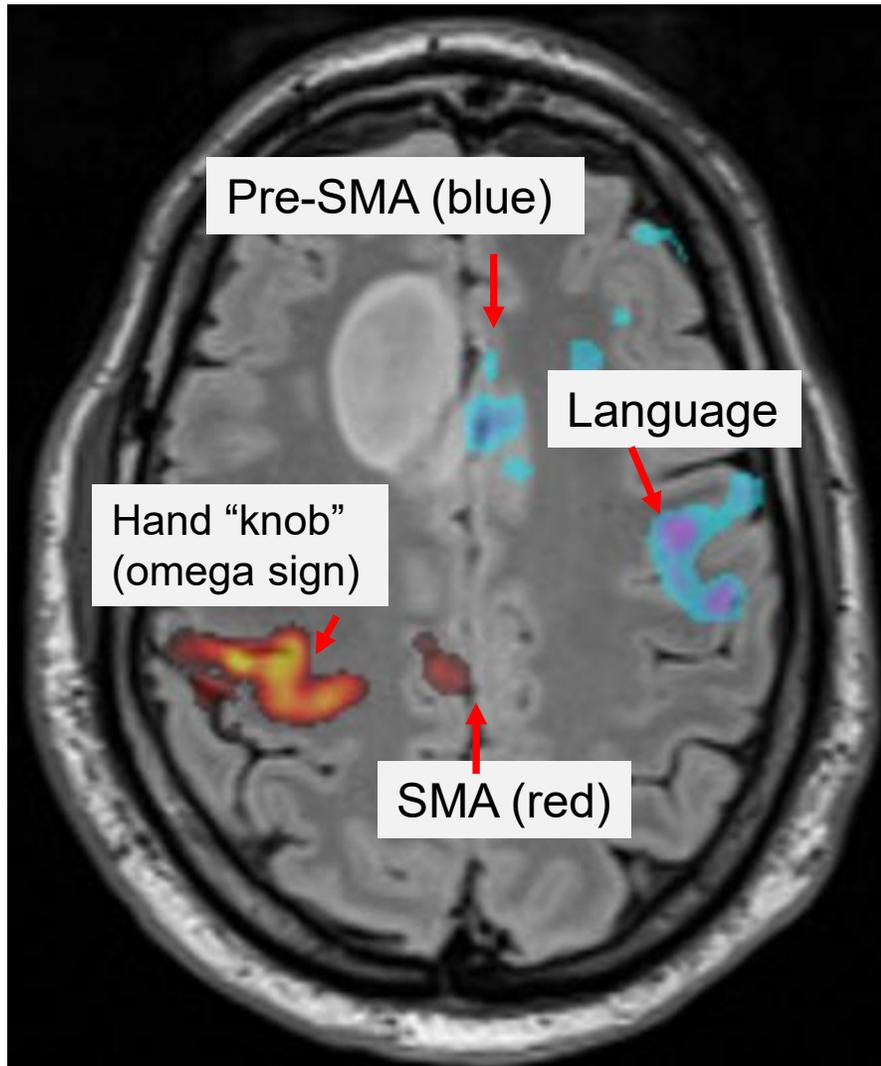
Regional contribution for language functions

Voets NL, Ashtari M, Beckmann CF, et al. Consensus recommendations for clinical functional MRI applied to language mapping. *Aperture Neuro*. 2025;5. doi:[10.52294/001c.128149](https://doi.org/10.52294/001c.128149) Consensus of guidelines for performing clinical fMRI for language. In depth coverage of clinical fMRI language mapping.



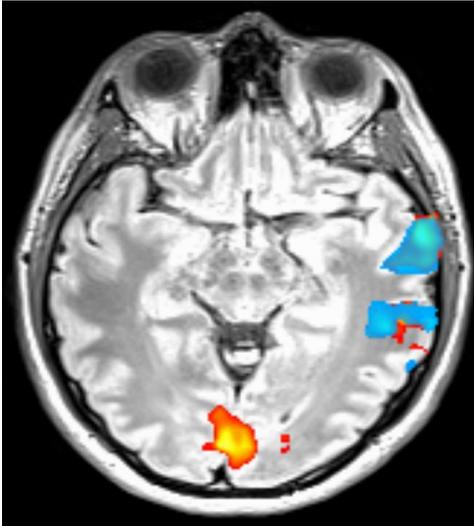
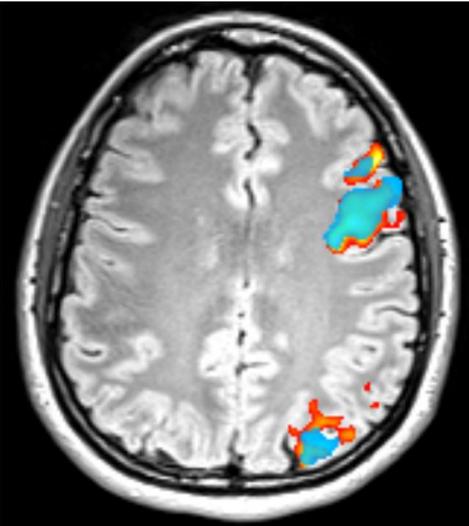
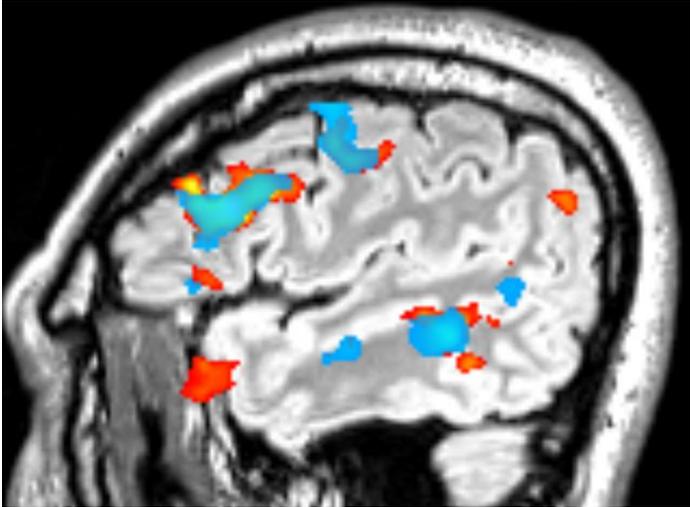
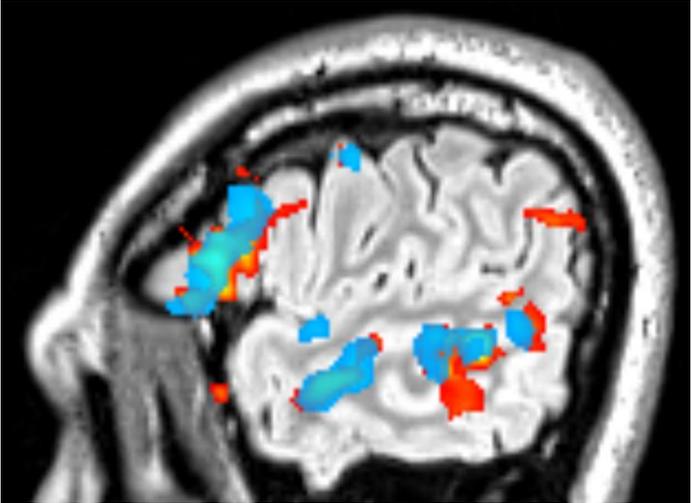
Frontal Lobe: Top-down control	Parietal Lobe: Attention, Prediction, Multimodal integration	Temporal Lobe: Categories & Meaning
Superior 1 pre-SMA Speech initiation & sequencing	Superior 8 aIPS Writing / orthographic working memory	Superior 11 PT/pSTG Phonological processing and integration 12 mSTG Phonological processing of words
Middle 2 Exner's Writing (and reading) 3 pMFG/IFS Cognitive control Area 55b Articulatory coordination & planning	Inferior 9 SMG Phonological (including grapheme) processing & working memory 10 Angular Multimodal semantic processing & integration, inc orthographic	Middle 13 pMTG Semantic-phonological integration 14 mMTG Semantic processing
Inferior 4 vPreM Phonological processing & articulation 5 Pop Phonological programming / control 6 Ptr Lexico-semantic integration & control 7 Por Associative semantic processing	SMA: supplementary motor area. pMFG: posterior middle frontal gyrus. IFS: inferior frontal sulcus. vPREM: ventral premotor. Pop: pars opercularis. Ptr: pars triangularis. Por: pars orbitalis. aIPS: anterior inferior parietal sulcus. SMG: supra-marginal gyrus. PT: planum temporale. pSTG: posterior superior temporal gyrus. mSTG: middle superior temporal gyrus. pMTG: posterior middle temporal gyrus. mMTG: mid-portion of middle temporal gyrus. TP: temporal pole. ant/midITG: anterior-to-mid inferior temporal gyrus. pITG: posterior inferior temporal gyrus. VOT: ventral occipito-temporal area. VWFA: visual word form area. BTLA: basal temporal language area.	Anterior 15 TP Semantic judgments & associations
Insula Complex articulatory planning		Inferior 16 ant/midITG Lexical retrieval & integration 17 pITG/VOTC VWFA-1: Lexical access & categorization (e.g., orthography)
		Basal 18 mid fusiform VWFA-2: integrating orthography with sound & meaning 19 ant fusiform BTLA: Lexical-semantic processing

Supplementary Motor Area (SMA) and pre-SMA



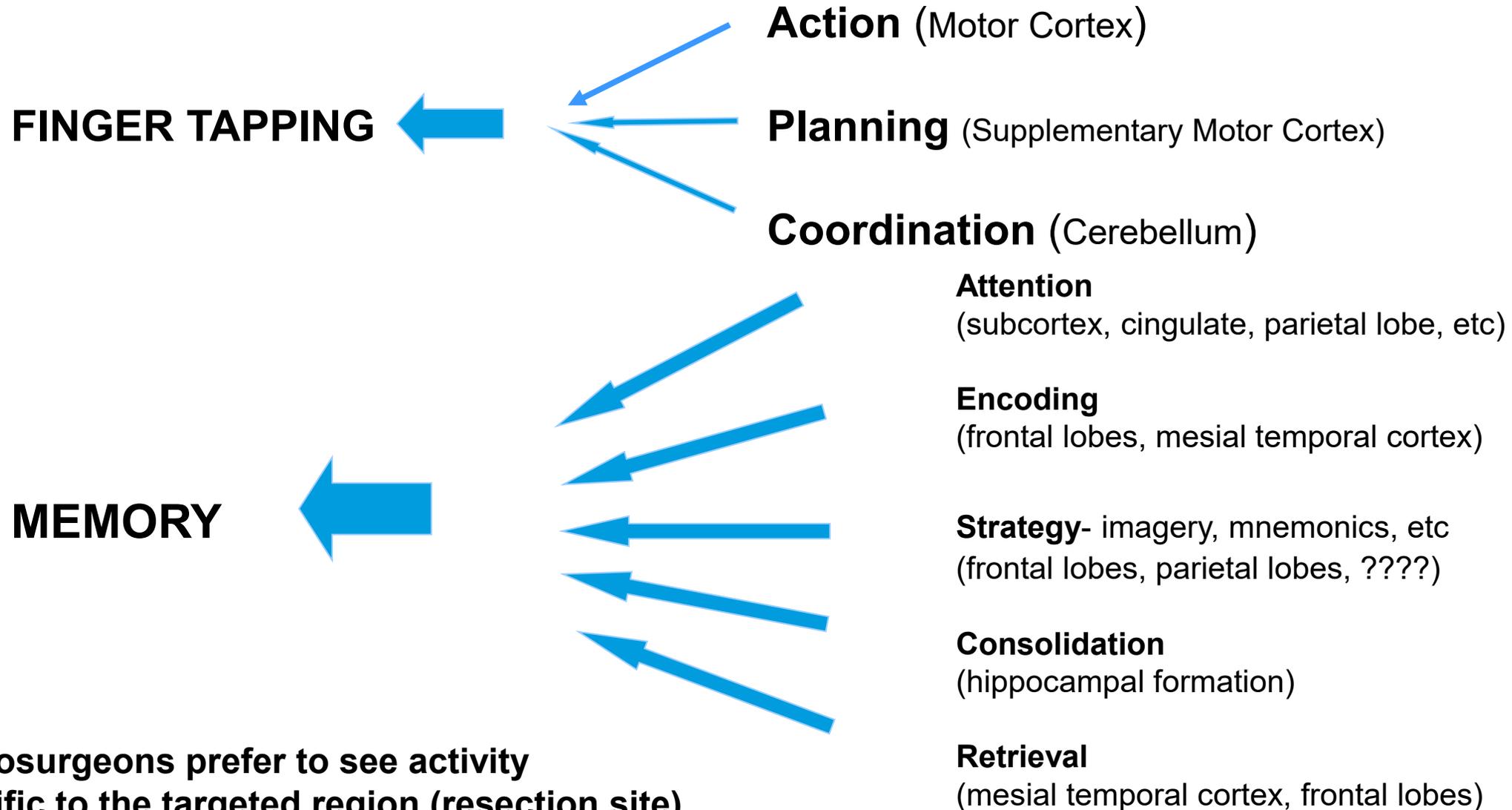
Frontal Aslant Tract

BILINGUALISM



Bilingual patient with
Small anterior tip lesion.
Red: Spanish language
Blue: English language

CREATING USABLE TASKS FOR PRE-SURGICAL MAPPING: COGNITIVE COMPLEXITY



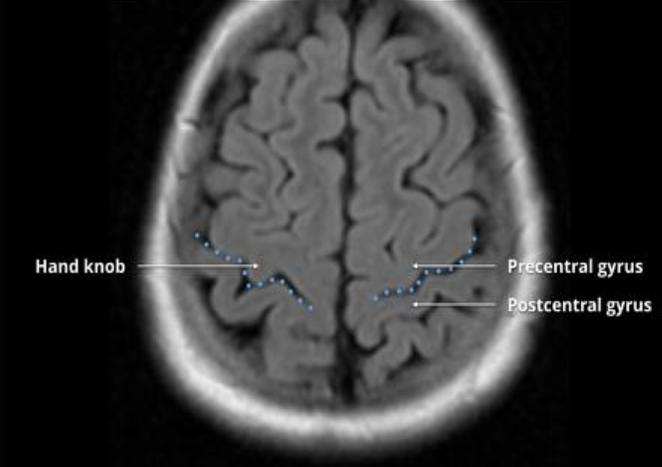
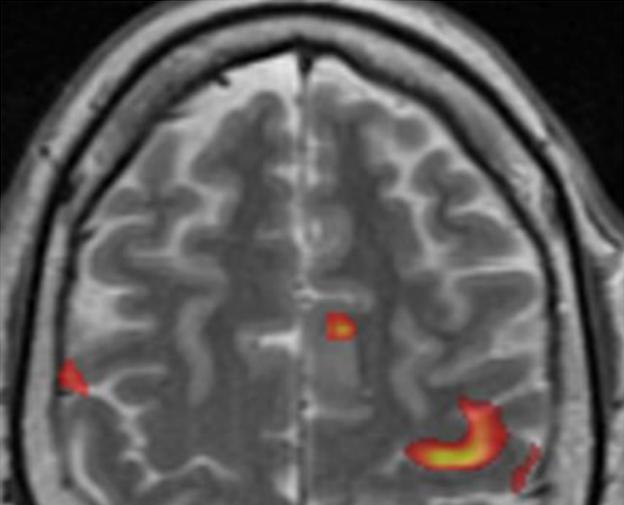
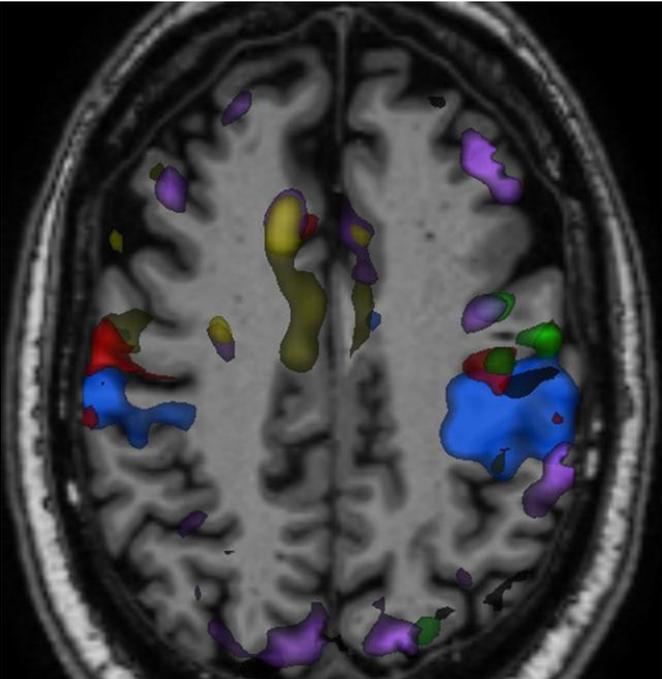
Neurosurgeons prefer to see activity specific to the targeted region (resection site), but we need to know the activity is representing the neural network

RESEARCH USE OF FMRI VS CLINICAL USE: CONVERSION OF FMRI TECHNIQUE FOR CLINICAL CASES

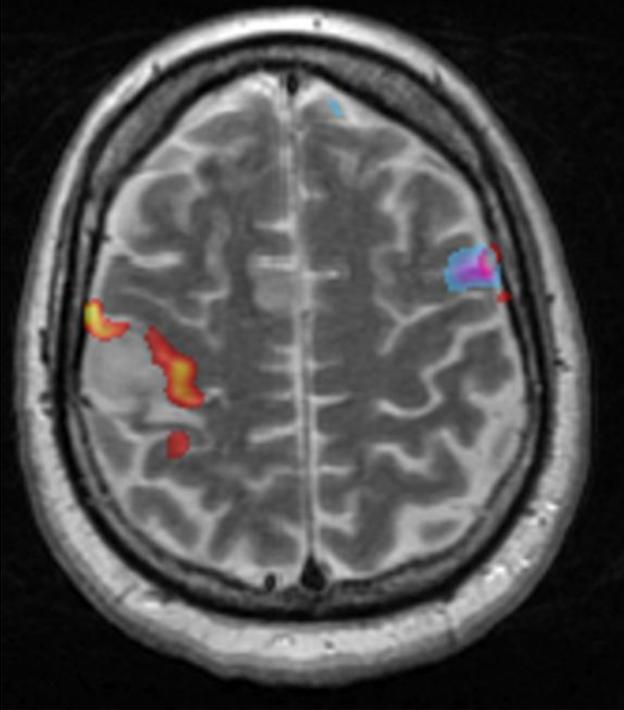
False positive vs. false negative errors

- False Positive Errors: Research studies need to avoid, for example, making claims about brain regions that participate in an activity (or stating a difference in regional brain activity between groups)
- False Negative Errors: When the question is whether an area of the brain can be resected, false negative errors are far more concerning.
 - FMRI protocols minimize false positive errors by:
 - Smoothing the data (2-4mm)
 - Redundantly mapping functions:
 - Motor: mapping several regions of the motor cortex
 - Language: mapping multiple tasks with overlapping function (conjunction analyses)

RESEARCH USE OF FMRI VS CLINICAL USE: CONVERSION OF FMRI TECHNIQUE FOR CLINICAL CASES

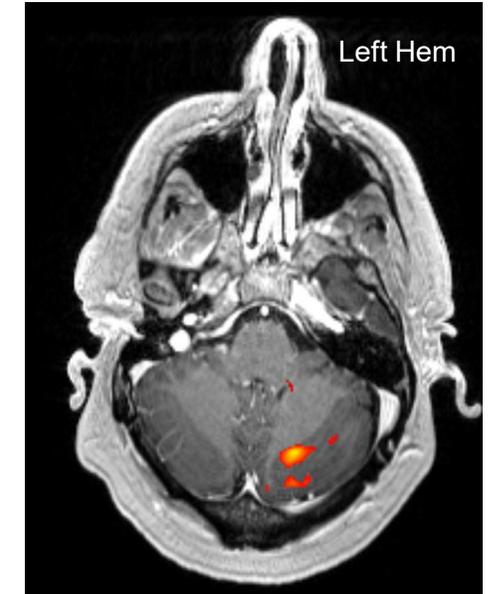
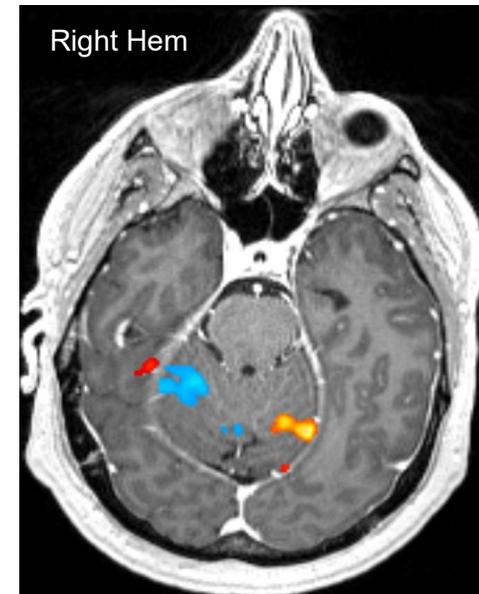
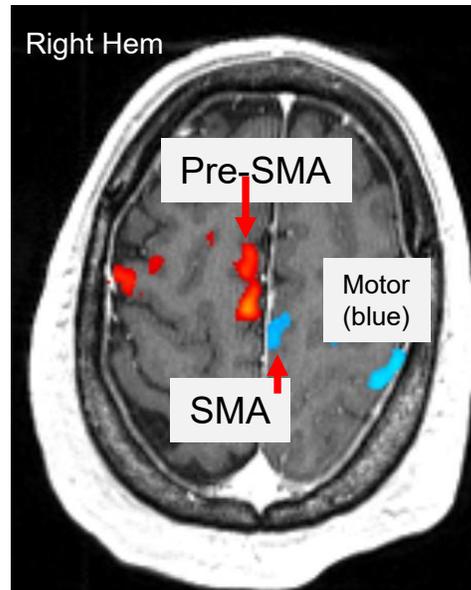
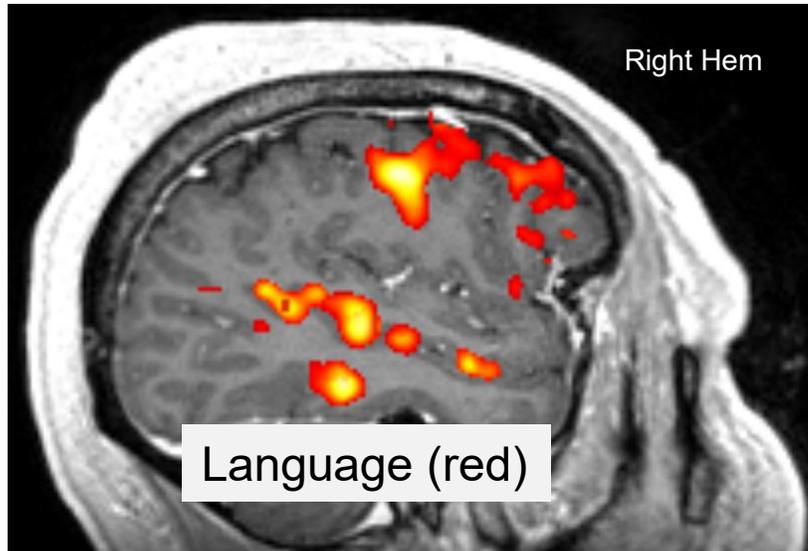
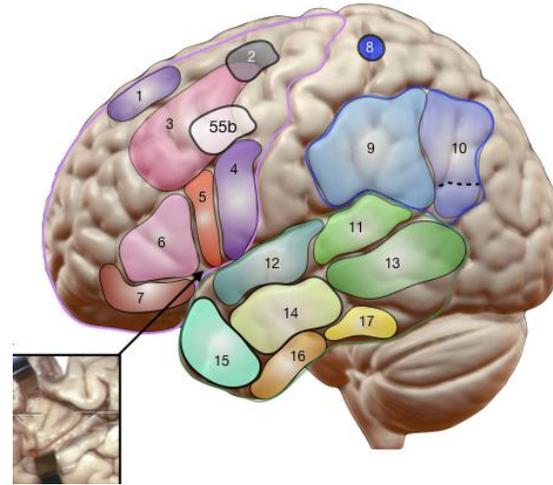


Central sulcus



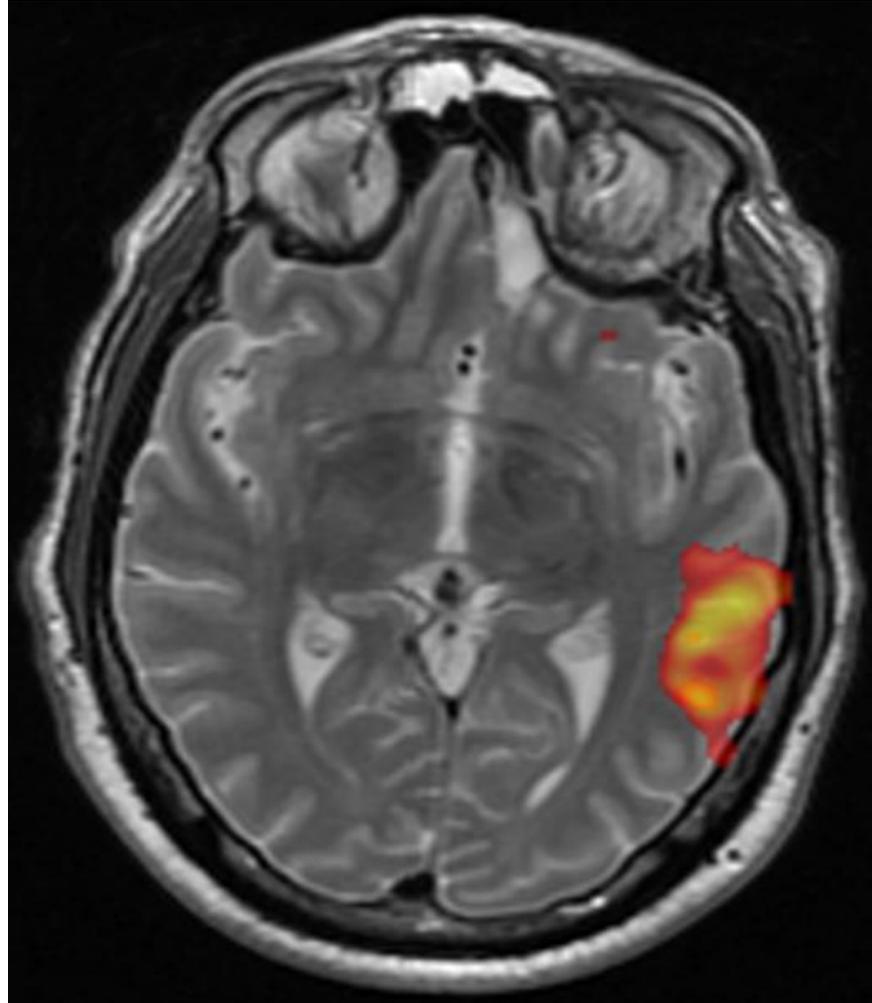
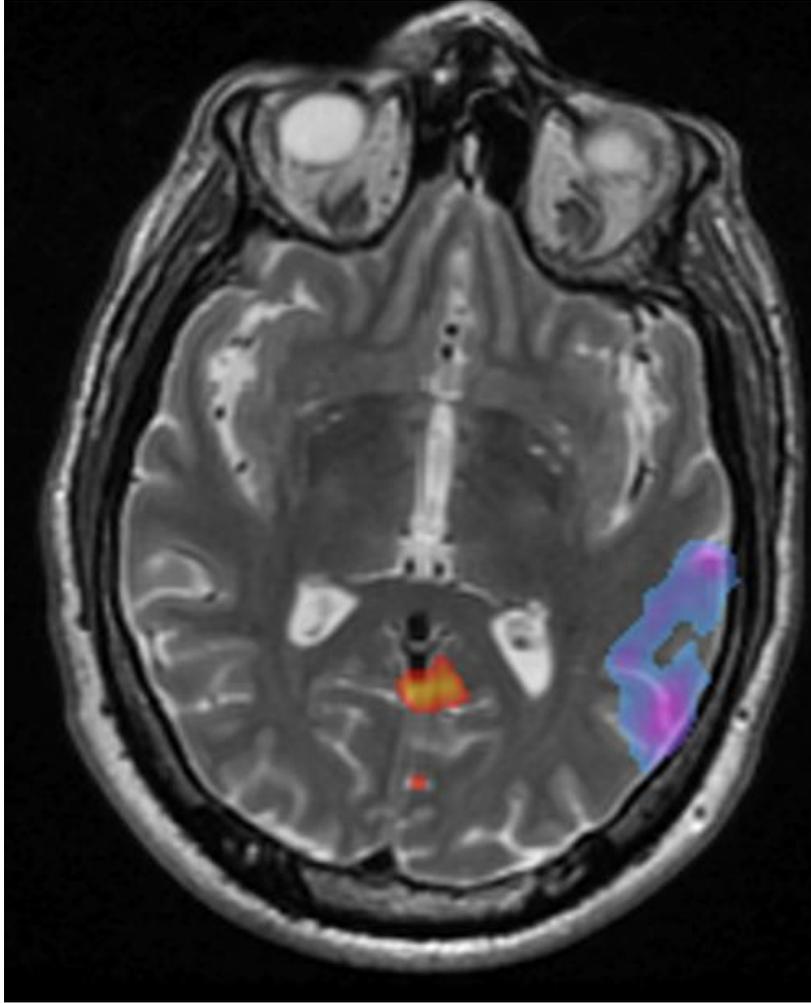
CASE OF RIGHT HEMISPHERE LANGUAGE DOMINANCE IN A RIGHT-HANDED PATIENT: NETWORK ACTIVITY ENSURES ACCURACY

48 y.o. right-handed man with a left temporal lobe GBM. Working, speech and language generally intact. Strongly right-handed, no family history of left-handedness

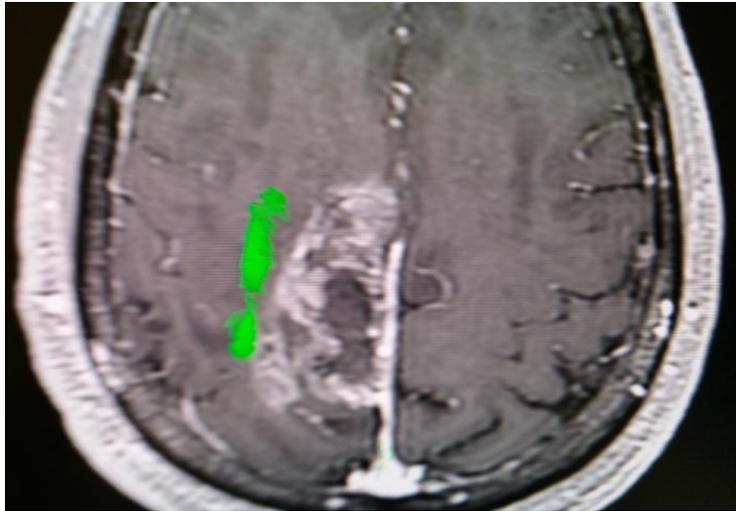


Shows RIGHT hemisphere language dominance

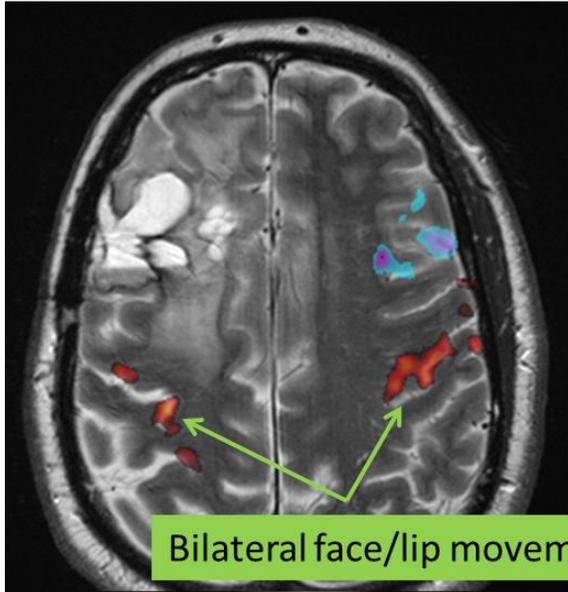
REPEATABILITY OF FMRI: 7 MONTHS APART



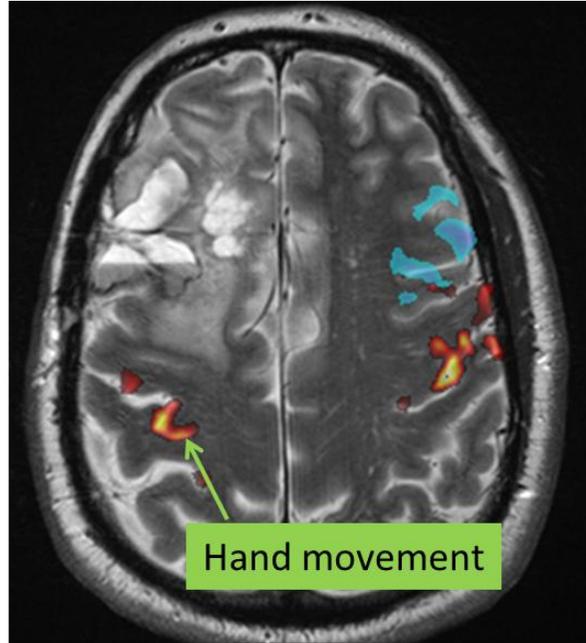
TRAJECTORY FOR SURGERY WHEN THERE IS A LOSS OF ARCHITECTURE DUE TO MASS EFFECT



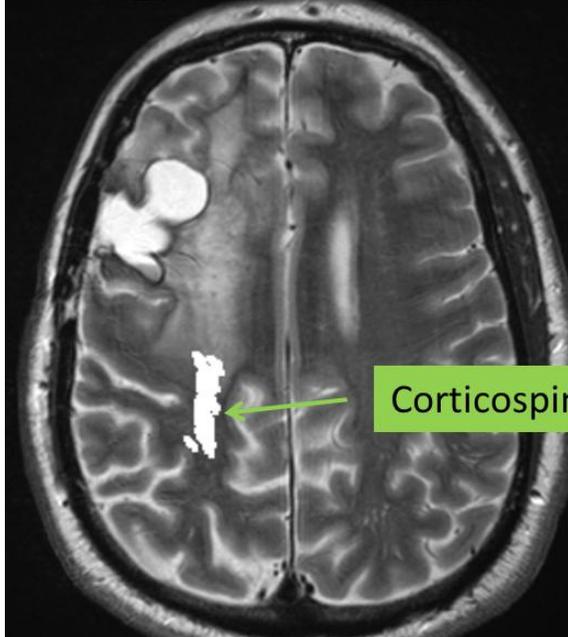
Combination of presurgical mapping procedures



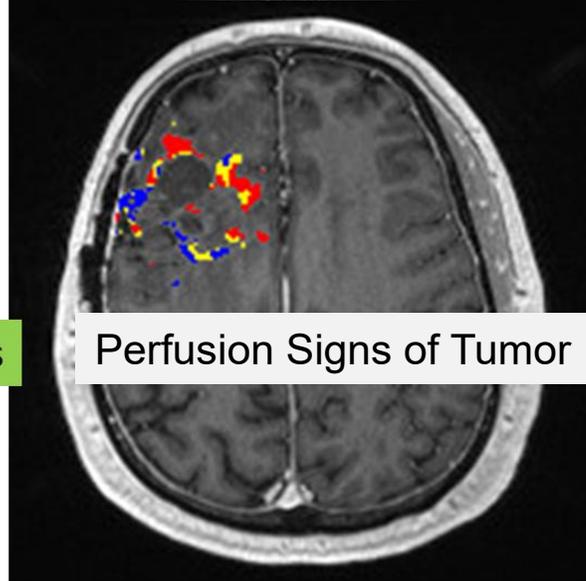
Bilateral face/lip movement



Hand movement



Corticospinal tracts



Perfusion Signs of Tumor

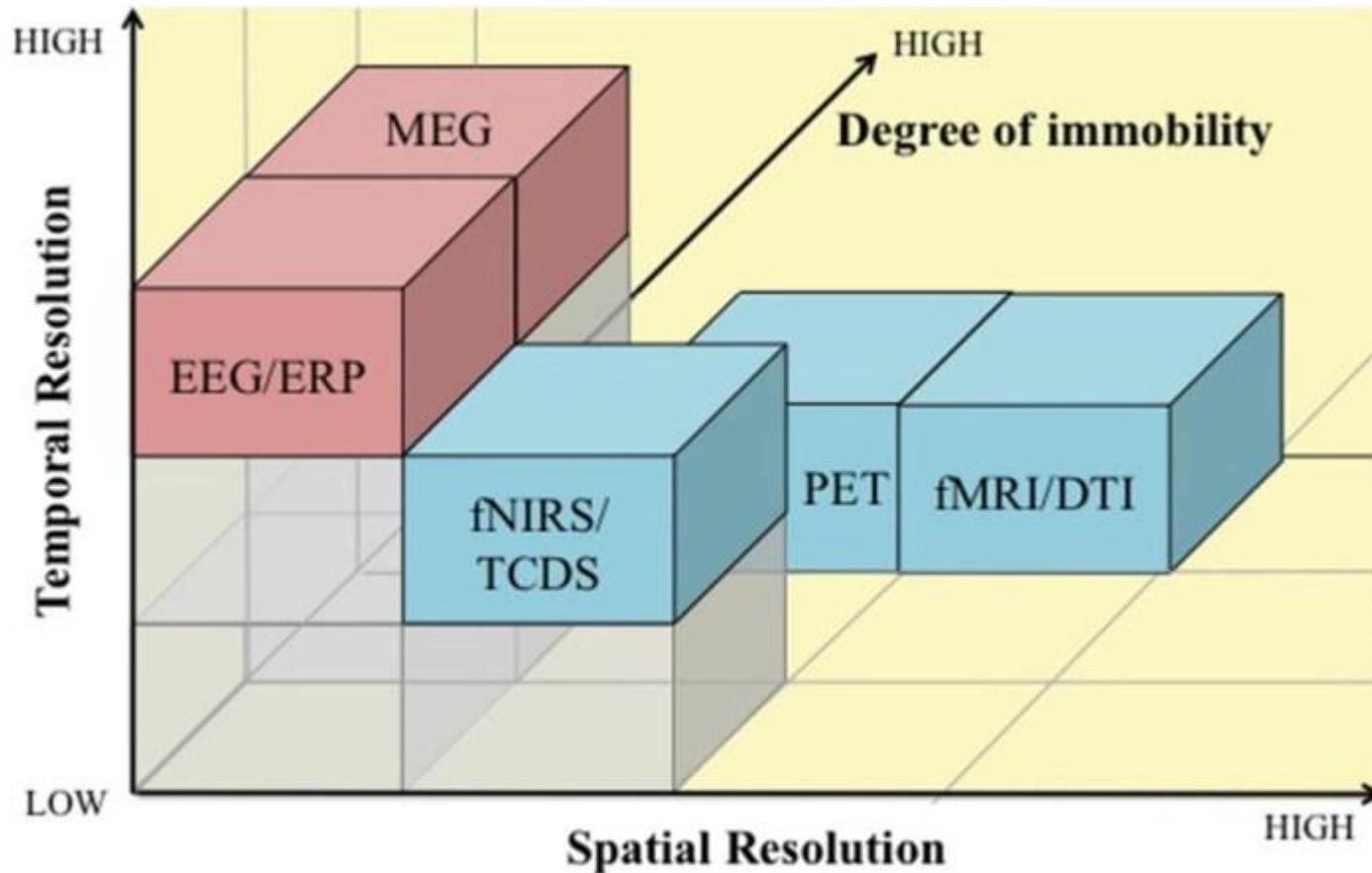
RESTING STATE fMRI

1. Clinical trial just completed using language rs-fMRI pre- and post-glioma resection. Study descriptions seems to compare the findings to NP data, but does not say whether there is a task-based fMRI task for comparison
2. rs-fMRI is difficult to analyze, no current commercial platforms
3. “Seed based” analyses but individual differences may make this a difficult approach (where does one place the seed?)
4. One interesting approach that is not “resting state”: active movie watching

COLLABORATIVE DECISION-MAKING

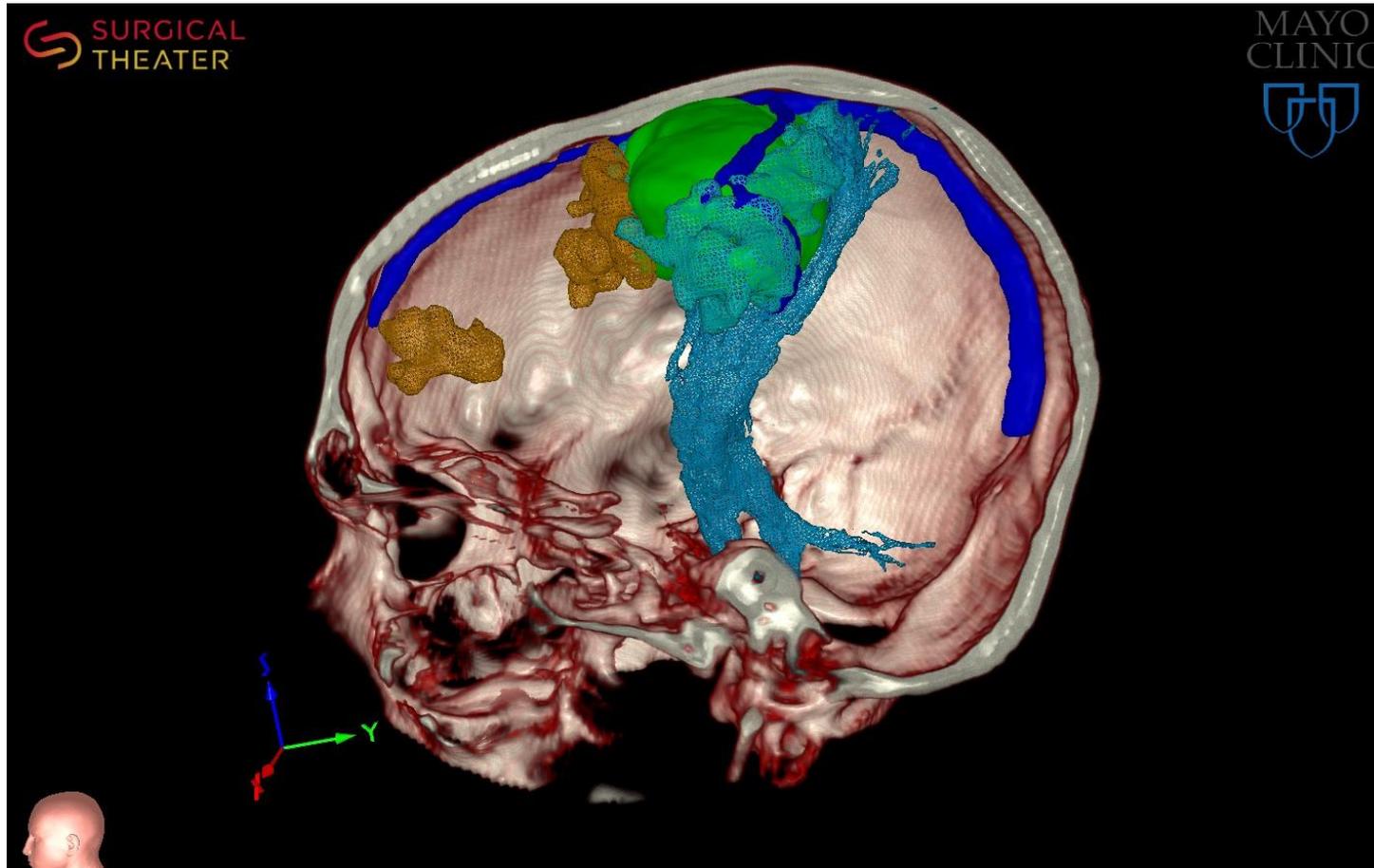


ALL MEASURES OF BEHAVIOR HAVE STRENGTHS/WEAKNESS



Mehta RK, Parasuraman R. Neuroergonomics: a review of applications to physical and cognitive work. *Front Hum Neurosci.* 2013 Dec 23;7:889. doi: 10.3389/fnhum.2013.00889. PMID: 24391575; PMCID: PMC3870317.

USING VIRTUAL REALITY FOR PATIENTS AND SURGEONS



References (selected, please see Voets et al. for many more):

1. Voets NL, Ashtari M, Beckmann CF, et al. Consensus recommendations for clinical functional MRI applied to language mapping. *Aperture Neuro*. 2025;5. doi:[10.52294/001c.128149](https://doi.org/10.52294/001c.128149) **Consensus of guidelines for performing clinical fMRI for language. In depth coverage of clinical fMRI language mapping. Has many relevant papers for fMRI brain mapping in general, language mapping specifically.**
2. Baxter LC. Functional MRI in the presurgical workup. In: Pearson C, Ecklung-Johnson E, Gale S, editor(s). *Neurosurgical Neuropsychology*. United Kingdom: Elsevier; 2018. p. 77-98. *Chapter in a book covering many aspects of clinical neuropsychology within the neurosurgical setting. The book will be updated soon.*
3. Official position of the division of clinical neuropsychology (APA division 40) on the role of neuropsychologists in clinical use of fMRI: approved by the Division 40 Executive Committee July 28, 2004. (2004). *Clin Neuropsychol*, 18(3), 349-351. doi:10.1080/1385404049088718
4. Filippi. (2016). *fMRI techniques and protocols* (Vol. 830). M. Filippi (Ed.). Milan, Italy: Humana press. *Book describing fMRI technique with chapters for major cognitive functions.*
5. Leclercq, D., Delmaire, C., de Champfleury, N. M., Chiras, J., & Lehericy, S. (2011). Diffusion tractography: methods, validation and applications in patients with neurosurgical lesions. *Neurosurgery Clinics*, 22(2), 253-268. *Has illustrations of how preclinical tractography is done.*
6. Middlebrooks, E. H., Yagmurlu, K., Szaflarski, J. P., Rahman, M., & Bozkurt, B. (2017). A contemporary framework of language processing in the human brain in the context of preoperative and intraoperative language mapping. *Neuroradiology*, 59(1), 69-87. *Comprehensive overview of language functional anatomy for presurgical assessment.*
7. Vysotski, S., et al. (2018). "Preoperative FMRI associated with decreased mortality and morbidity in brain tumor patients." *Interdisciplinary Neurosurgery* 13: 40-45. *Large single center study showing improved morbidity and mortality in brain tumor patients with fMRI use.*

References (selected, please see Voets et al. for many more):

1. Luna, L. P., Sherbaf, F. G., Sair, H. I., Mukherjee, D., Oliveira, I. B., & Köhler, C. A. (2021). Can preoperative mapping with functional MRI reduce morbidity in brain tumor resection? A systematic review and meta-analysis of 68 observational studies. *Radiology*, *300*(2), 338-349.
2. Mehta RK, Parasuraman R. Neuroergonomics: a review of applications to physical and cognitive work. *Front Hum Neurosci*. 2013 Dec 23;7:889. doi: 10.3389/fnhum.2013.00889. PMID: 24391575; PMCID: PMC3870317.
3. Massot-Tarrús, A., & Mirsattari, S. M. (2022). Roles of fMRI and Wada tests in the presurgical evaluation of language functions in temporal lobe epilepsy. *Frontiers in Neurology*, *13*, 884730.
4. Gordon, E. M., Chauvin, R. J., Van, A. N., Rajesh, A., Nielsen, A., Newbold, D. J., ... & Dosenbach, N. U. (2023). A somato-cognitive action network alternates with effector regions in motor cortex. *Nature*, *617*(7960), 351-359. *Fascinating evidence for a change in the historical “homunculus” that better explains how the motor cortex coordinates with other regions.*
5. Turker, S., Kuhnke, P., Eickhoff, S. B., Caspers, S., & Hartwigsen, G. (2023). Cortical, subcortical, and cerebellar contributions to language processing: A meta-analytic review of 403 neuroimaging experiments. *Psychological Bulletin*, *149*(11-12), 699.
6. Vergani, F., Lacerda, L., Martino, J., Attems, J., Morris, C., Mitchell, P., ... & Dell'Acqua, F. (2014). White matter connections of the supplementary motor area in humans. *Journal of Neurology, Neurosurgery & Psychiatry*, *85*(12), 1377-1385.