Quality Assurance for Performing an Optimal fMRI Study: Tips and Tricks from Our Clinical Experience

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Introduction:

Multiple steps are necessary for optimization of a functional magnetic resonance imaging (fMRI) study. These include patient training, fMRI scan acquisition, data post-processing, and quality assurance (QA) as well as image interpretation. Attention to detail is key. A high quality scan is the result of the cumulative effect of multiple factors which occur during each of these steps. Our aim is to outline how a typical fMRI scan is acquired at our institution, beginning with patient training and continuing through data post processing and QA. Finally, we will discuss a few pearls that we find helpful to keep in mind during image interpretation. This poster is by no means a comprehensive review of clinical fMRI, but, rather, should serve as the framework on which a clinical fMRI program can be developed.

Patient Training:

- At our institution, patient training is typically performed by a physician who serves as our fMRI coordinator or, if the physician is unavailable, a qualified MRI technologist.
- The patient's clinical history and prior imaging should be reviewed prior to training and image acquisition.
    → Tasks may be added or removed based on lesion location. For instance, adding an auditory task for a lesion near Heschl's gyrus. (Fig 1.1)
    → Performed in conjunction with the neuroradiology fellow and/or attending on the fMRI service for the day.
- Ask the patient what symptoms they are experiencing.
    → Focus on paradigms with expected activation nearby.
    → If patients have weakness in a limb, paired tasks such as bilateral finger tapping can be separated into different right finger/left finger tasks.
    → Patients with leg paralysis can imagine moving leg. Alternatively, touch or movement may generate passive tactile or proprioception activation, albeit weaker than active tasks.
- Training should be tailored to a patient's cognitive skills/aptitude.
    → A patient with impaired cognition or difficulty learning tends to perform better with more practice.
    → A patient with normal cognition and intact learning often performs better following a brief training session.
- Tasks should be performed using a language in which the patient is fluent.
    → A native Tagalog speaker (Philippines) was able to perform tasks and achieve robust language activation. (Fig 1.2)
    → When unable to read in scanner (for any reason), can do motor task with colors: green (go) and red (stop).
- Establish a rapport with the patient and answer all questions.
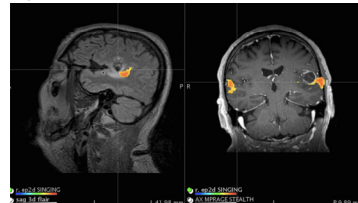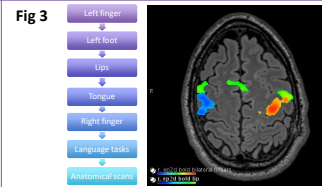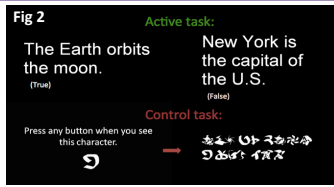   → An informed patient is a motivated patient.

Fig 1.1   Fig 1.2

Paradigms:

- Vary from basic motor tasks to complex language tasks, the latter are performed to keep patients engaged and challenged.
- We also perform a cerebrovascular reactivity (CVR) paradigm to determine what brain regions can generate BOLD signal.
- Paradigms use block design with 20s active and 20s control blocks.
    → Reading comprehension paradigm – Read sentences and decide if true or false (active). Locate a previously seen symbol among a group of symbols (control). (Fig 2)
    → CVR paradigm – Hold breath (active) and breath normally (control).

Fig 2
Active task:
The Earth orbits the moon. (True)
New York is the capital of the U.S. (False)
Control task:
Press any button when you see this character.

Fig 3
Left finger, Left foot, Lips, Tongue, Right finger, Language tasks, Anatomical scans

Image Acquisition:

- Patient comfort is essential. Even a claustrophobic patient can perform well on an fMRI with the right approach.
    → Instruct the patient to keep their eyes closed during scan set up and to open them only when ready to run paradigm.
- Use appropriate MRI safe glasses if the patient has a prescription.
- Remind patients to keep head stationary throughout study.
    → This limits need for manual correction during post-processing.
- Functional tasks should be run in decreasing order of importance to avoid mental fatigue while performing most important tasks.
    → For a lesion near the hand knob, consider scan order in **Figure 3**.
- Examine real-time BOLD activation during scan to gauge performance.
    → Stop and repeat tasks if needed to save time and increase efficiency.
- Observe patients during scan (especially motor tasks) to ensure task is being performed with minimal whole body motion.
    → Helps understand reasons for poor observed activation.
- Adjust FOV to cover region of interest and surrounding eloquent areas.
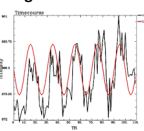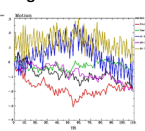

Fig 4.1   Fig 4.2   Fig 5
(a) CVR with ideal response throughout brain.
(b) CVR with no response in brain surrounding lesion.
(c) CVR with steal (i.e. negative response) due to AVM.
Fig 4.3
Training Assessment: ep2d reading comprehension
Trainer's Name: nmh
Patient's Self Assessment: 3 – performs adequately
Observer's Assessment: 3 – performs adequately
Scanning Assessment:
Operators' Name: JH
Patient's Self Assessment: 2 – performs marginally
Observer's Assessment: 2 – performs marginally
Image Quality Assessment: 3 – adequate
Correct Responses: 42.1%
Response Latency: 2.1 sec
Waveform Cluster Size: 2165.0 ul
Maximum RMSE in Motion Correction: 32.23
Motion correlation to ideal waveform. No motion parameters were well correlated.
Fig 6
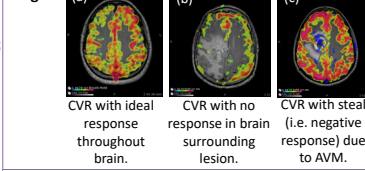AVM case where left finger activation has partially trans-located to left cerebral hemisphere.

Image Post-processing and Quality Assurance:

- Manually confirm accurate co-registration for anatomic sequences, fMRI tasks and DTI.
- Use smoothing function for noisy data and censor large motion spikes.
- Review the time-series for each task to ensure that the BOLD response (black) reasonably approximates the ideal waveform (red). (Fig 4.1)
- Limited motion in all 6 planes (i.e. < 5mm). (Fig 4.2)
- Check the motion parameters to make sure that the motion graph does not correlate with the ideal waveform, and therefore exclude motion as artifactual activation. (Fig 4.3)
- When sending anatomic images to PACS with multiple tasks overlaid, use different colors for each task.
- Alternately, can use activation blobs/outlines which are transparent centrally (i.e. loops/outlines) instead of solidly filled with color to see the borders of each task precisely.
- When in doubt regarding the validity of an activation cluster, usually activation that survives a high threshold is more accurate than one that is only present at a lower threshold.

Fig 7
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In this fMRI exam, the patient had good language activation during the reading comprehension paradigm even though a low score of 42.1% was reported.

This can result from obtaining a very good score on the active task and a very poor score on the control task.

Image Interpretation Pearls:

- BOLD imaging uses blood flow to the cortex as a surrogate marker for neuronal activity, rather than direct measurement.
- CVR measurement demonstrates cortex which is capable of generating BOLD signal, regardless of the presence of functioning neurons. (Fig 5)
    → Absent blood flow augmentation in response to hypercapnia (holding breath) can indicate neurovascular uncoupling.
    → Negative CVR signal can indicate steal physiology.
- Ignore obviously false BOLD activation.
    → Skull base activation on tongue motor task may be seen due to translated osseous motion during tongue movement.
- Consider the possibility of neural plasticity when an activation cluster appears genuine but is in an unexpected location. (Fig 6)
- Realize that activation may localize to the artery or draining vein supplying the region of interest but upstream or downstream to the cortex.
- Hemispheric language dominance is generally very reliable in fMRI.
- Temporal lobe language activation areas are usually more true to intraoperative cortical stimulation findings than frontal and parietal lobe language activations.
- For tasks that document patient performance, review the patient performance scores. A poor score often indicates a task that is unlikely to find activation clusters.
    → Discuss patient performance with the fMRI coordinator or MRI technologist to gather better insight into a poor score.
    → A 50% score could be the result of poor overall performance OR result from 100% correct on the active task and 0% correct on the control task. (Fig 7)