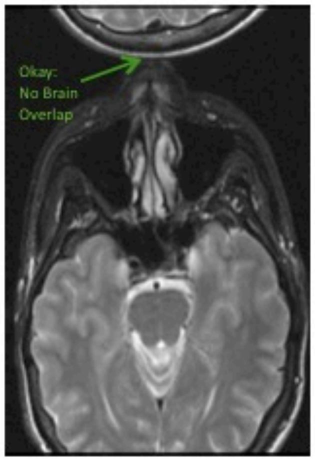
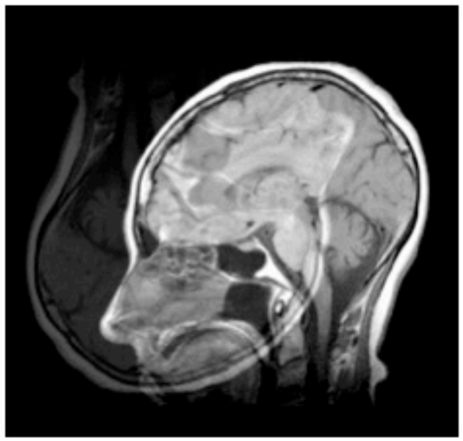
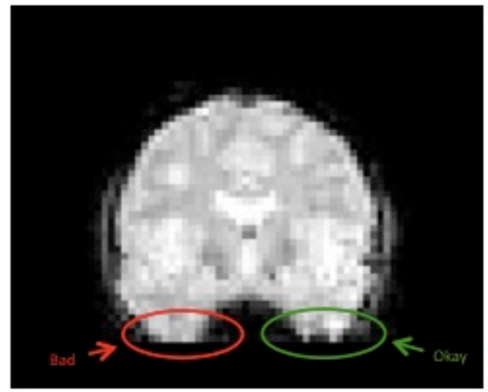
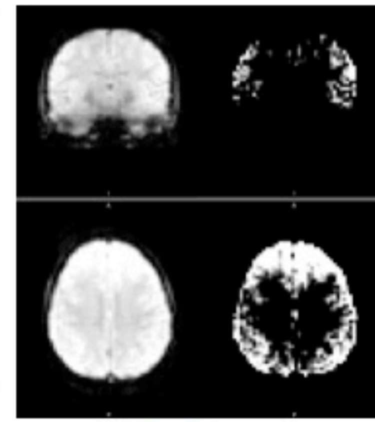
Qualitative Quality Control Manual

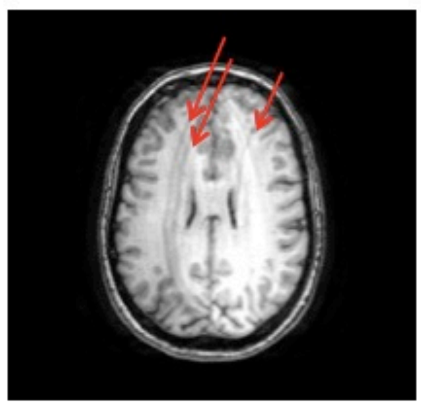
Artifacts in Structural and Functional MRI

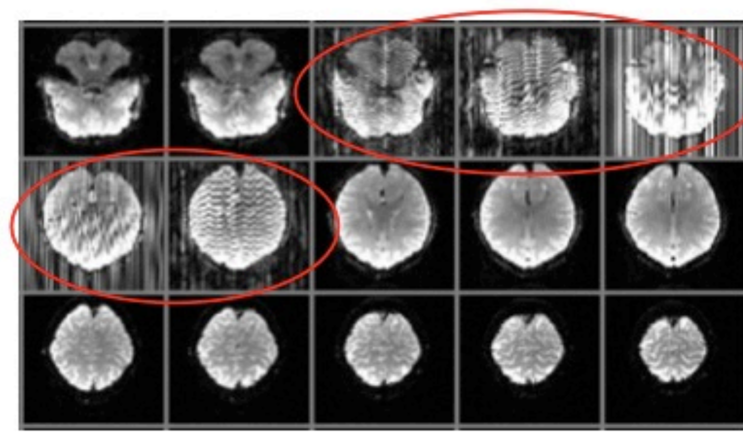












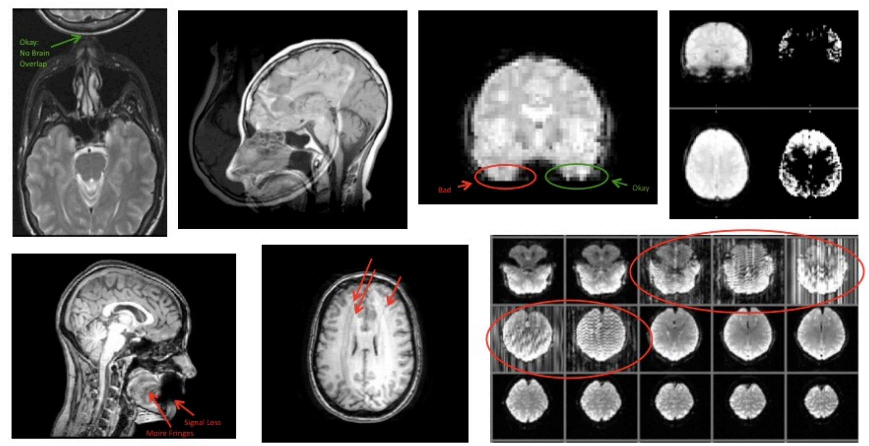
Qualitative MRI Quality Control

QC by the trained eye….

Some factors that can compromise data quality are so far only detectable by manually scrolling through each slice of RAW data to look for visible distortions called “**artifacts**”.

Examples of MRI artifacts:

- Field of View (FOV) clipping anatomy
- Wrapping
- Signal Loss/Susceptibility Artifact
- Ringing, Striping, or Blurring (structural scans)
- Ghosting
- Radio Frequency Noise/Spiking
- Signal Inhomogeneity
- Motion Slice Artifact (functional scans)



What causes MRI artifacts?

Experimenter Error:

- Field of View (FOV) positioned wrong –> brain image clipped -> "Wrapping"
- Forgot to remove all metal -> signal loss -> "Susceptibility Artifact"

Subject Motion:

- Ringing, Striping, or Blurring (in structural scans)
- "Motion Slice Artifact" (in functional scans)

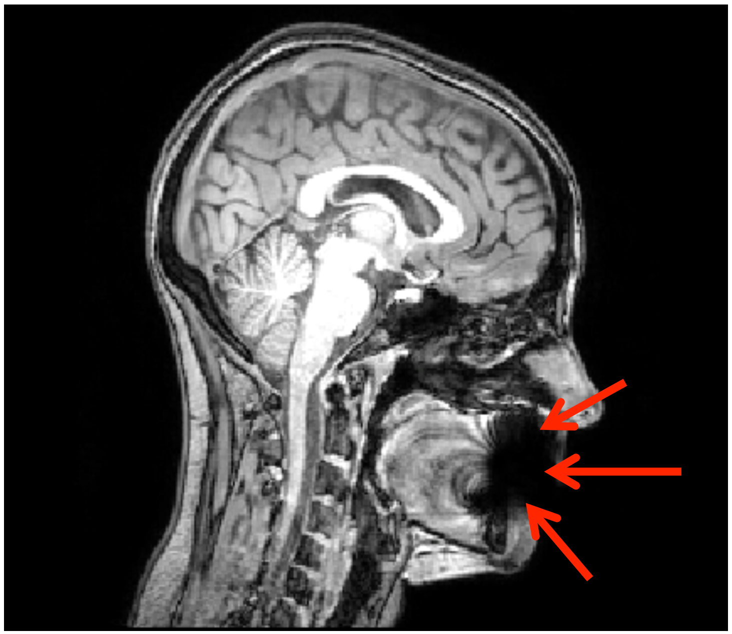
Problems with the Scanner/Head Coil:

- Radio Frequency Noise/Spiking
- Signal Inhomogeneity

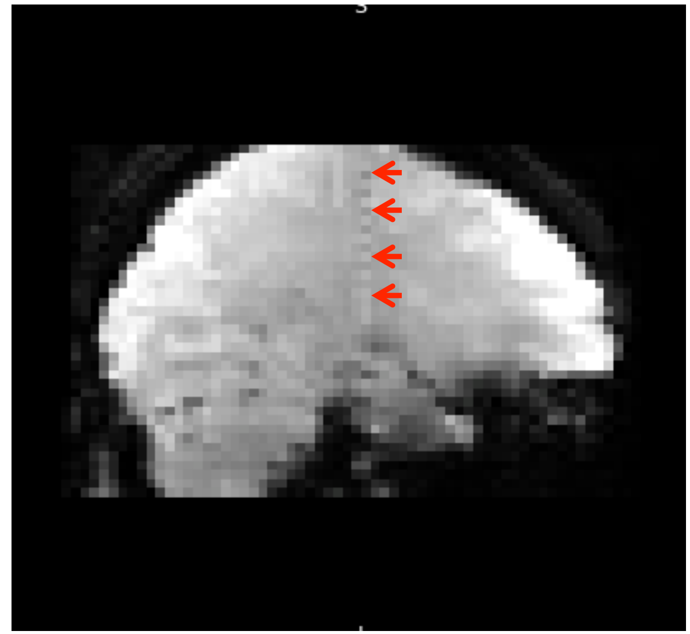
Artifacts from Image Reconstruction:

- Consistent low-level "Ghosting"
- Some types of "Ringing" (e.g. "Shadowed Arc Artifact" in structural scans)

How do you detect artifacts?

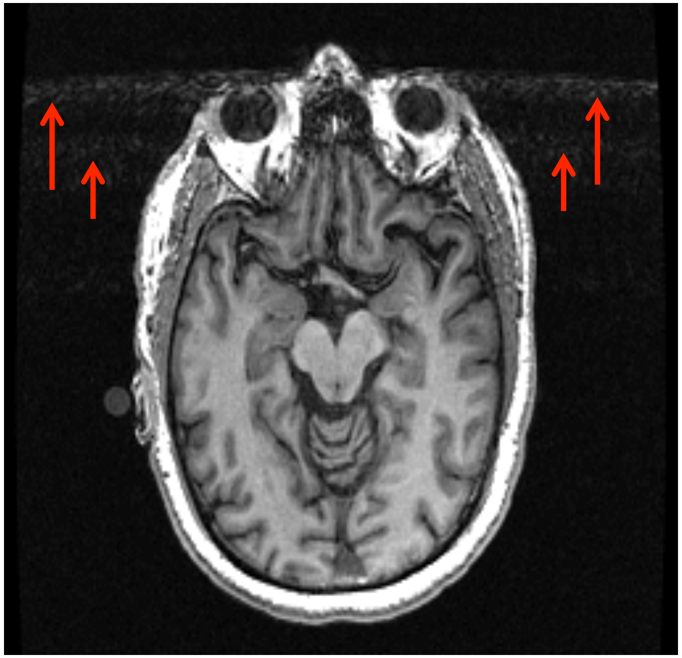


Some artifacts are hard to miss

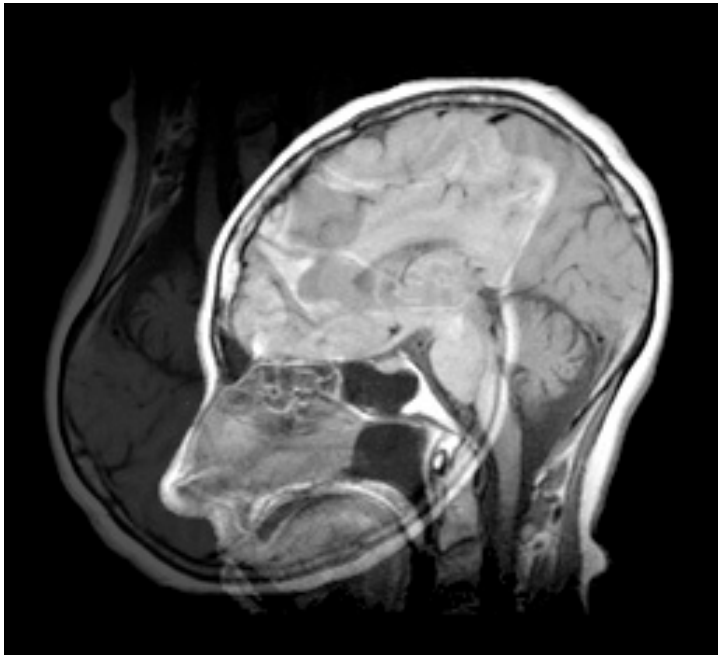


Others are incredibly subtle

When are artifacts a problem?



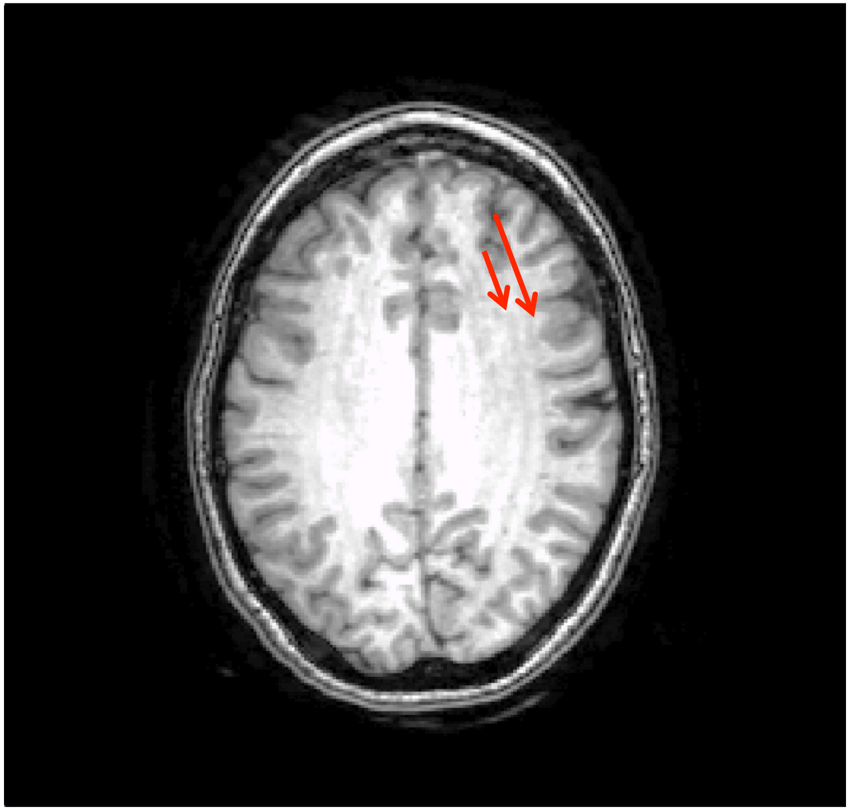
Some artifacts don't affect data quality



Others render it unusable

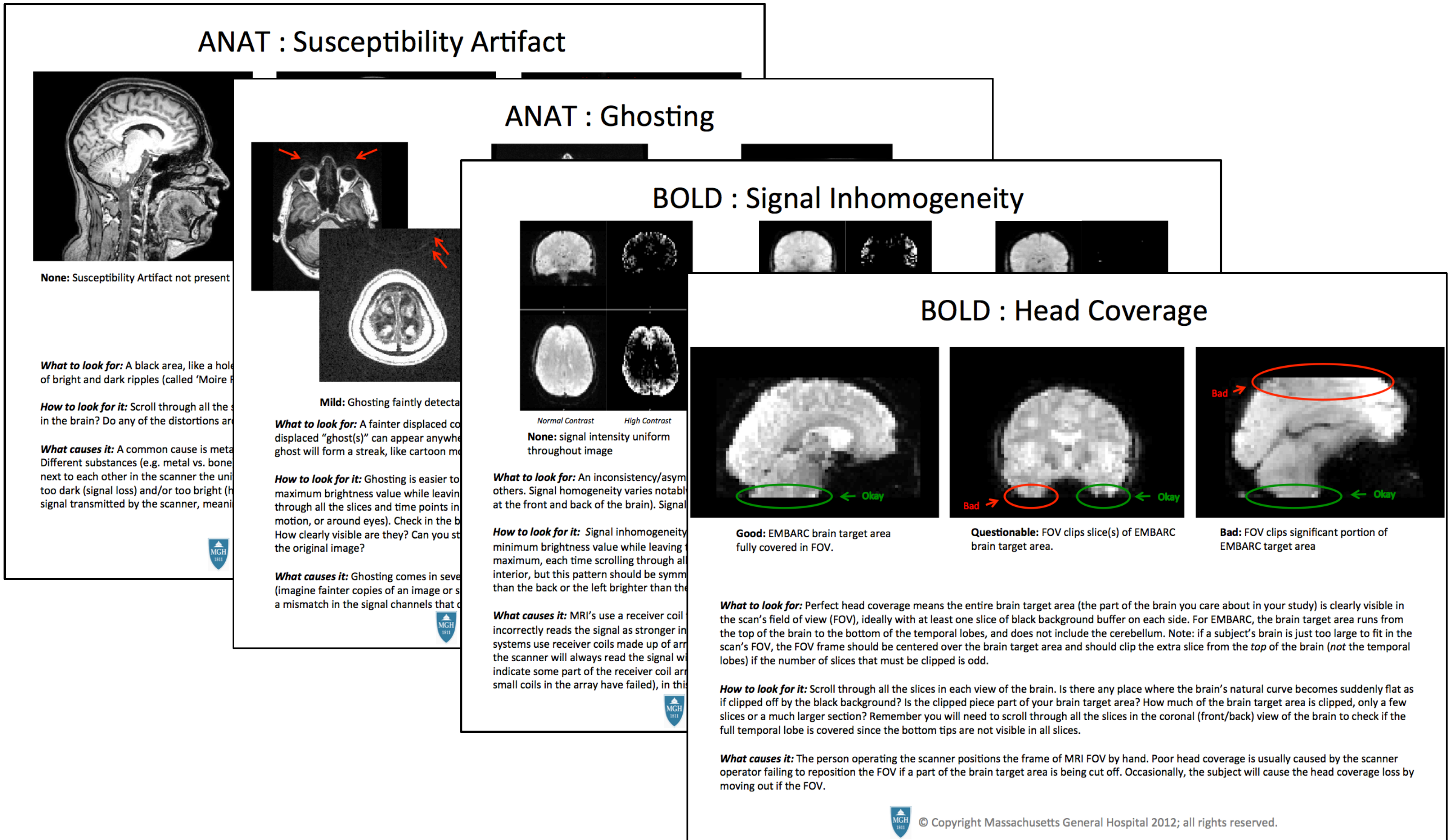
Training the Eye…

The intention of this manual is to familiarize you with the various types of artifacts and their levels of severity so you will be able to recognize them in your own data and make an informed decision for yourself about whether or not they affect your data quality.



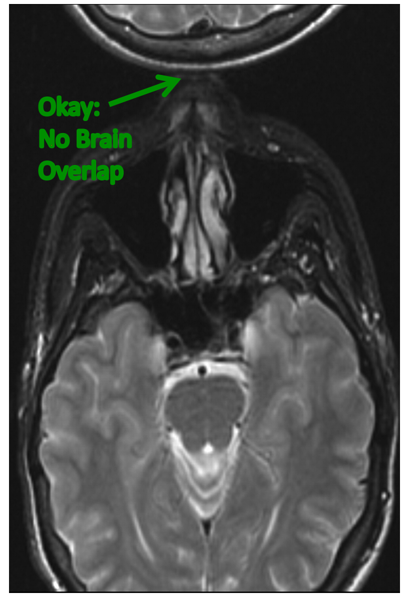
MRI Quality Control Manual

What to look for and How to look for it!

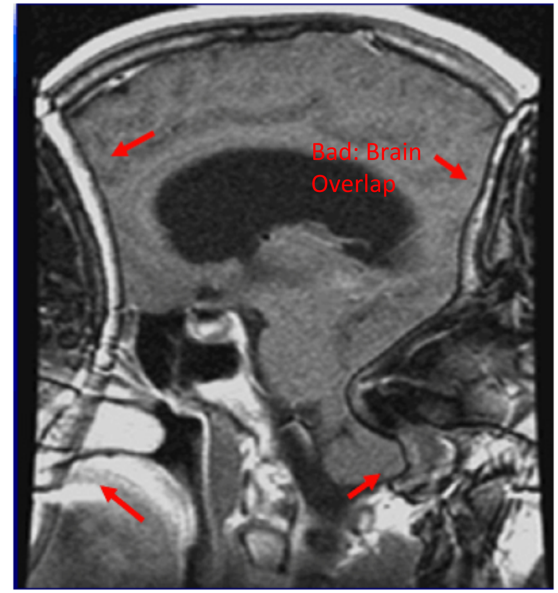


ANAT : Wrapping

Mild: head wrapping, but does not affect brain



Moderate: brain wrapping but not overlapped by other anatomy



Severe: brain wrapping and overlapped by other anatomy

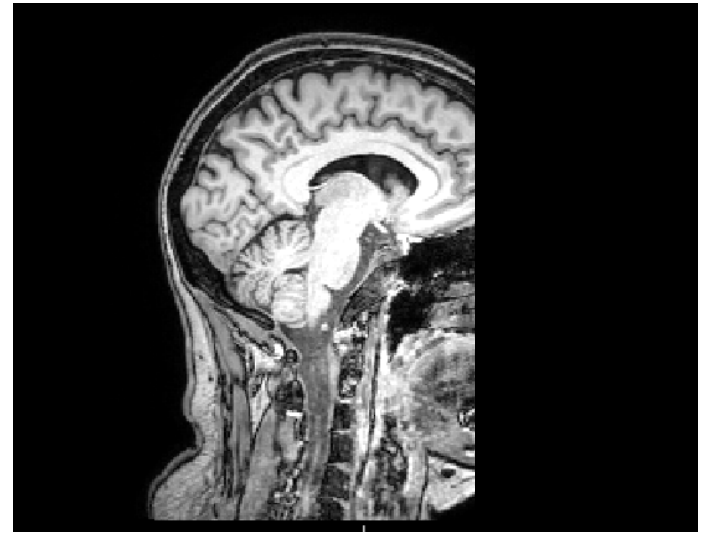
What to look for: A place where the scan frame cuts off part of the head and that missing piece appears on the far side of the image as if it were "wrapped" there. Wrapping becomes a serious problem only when wrapping anatomy overlaps the brain.

How to look for it: Scroll through all the slices in each view of the brain. Does the edge of the field of view cut off part of the head and can you see the missing piece on the far side of the image? Is the brain cut off? Does the wrapping piece of anatomy overlap the brain?

What causes it: Like a camera, the MRI should only take a picture of what falls inside the frame of its field of view. However, unlike a camera, the MRI can still pick up a signal from the body parts just outside its FOV and sometimes incorrectly maps them into the scan but wrapped onto the far side of the image because of frequency reversal in the image reconstruction.

ANAT : Head Coverage

Good: brain fully covered in FOV.



Bad: FOV clips brain

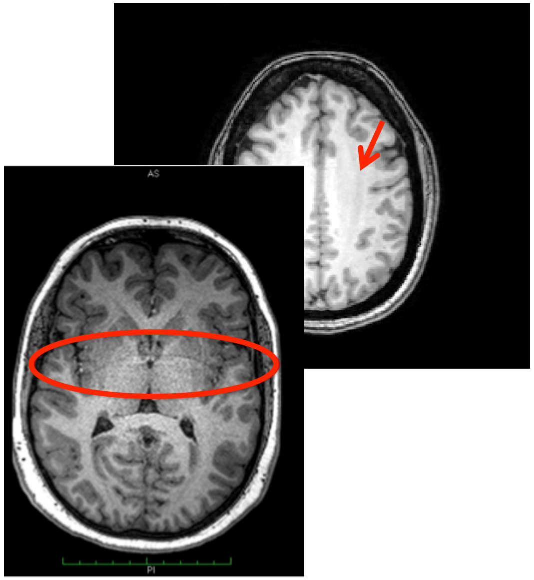
What to look for: Perfect head coverage means the entire brain target area (the part of the brain you care about in your study) is clearly visible in the scan's field of view (FOV), ideally with at least one slice of black background buffer on each side. For EMBARC*, the brain target area runs from the top of the brain to the bottom of the temporal lobes, and does not include the cerebellum. Note: imperfect head coverage with no wrapping is almost never seen in anatomical scans.

How to look for it: Scroll through all the slices in each view of the brain. Is there any place where the head's natural curve becomes suddenly flat as if clipped off by the black background? Does the clipping cut off any portion of the brain?

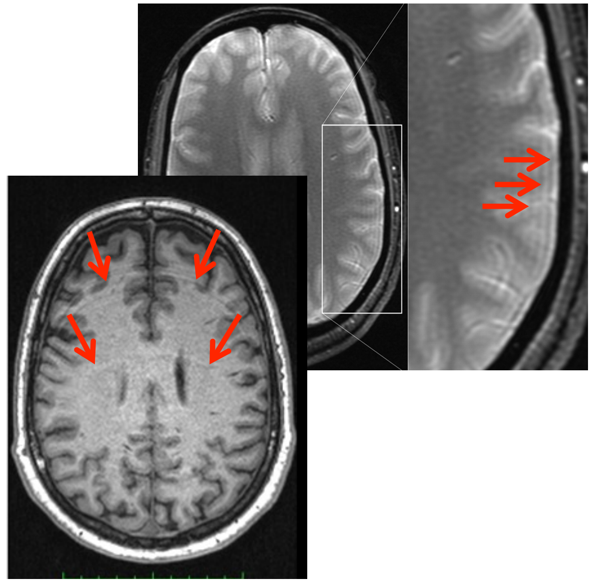
What causes it: The person operating the scanner positions the frame of MRI FOV by hand. Poor head coverage is usually caused by the scanner operator failing to reposition the FOV if a part of the brain target area is being cut off. Occasionally, the subject will cause the head coverage loss by moving out if the FOV.

* Establishing Moderators/Biosignatures of Antidepressant Response in Clinical Care (EMBARC) is a multi-site NIMH-funded study used in the creation of this manual

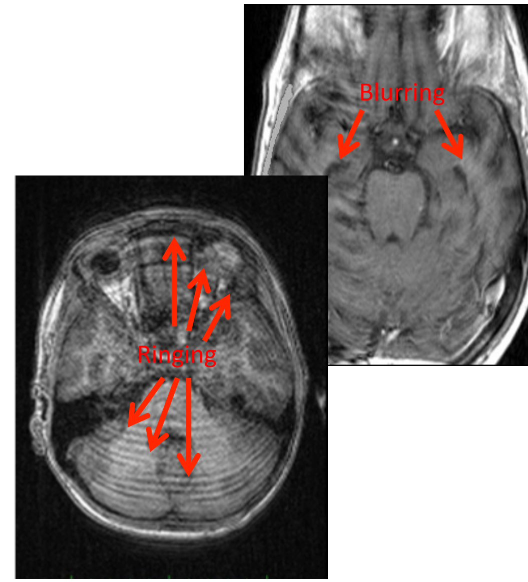
ANAT : Ringing, Striping, Blurring



Mild: Ringing, Striping, Blurring faintly detectable



Moderate: Ringing, Striping, Blurring pronounced



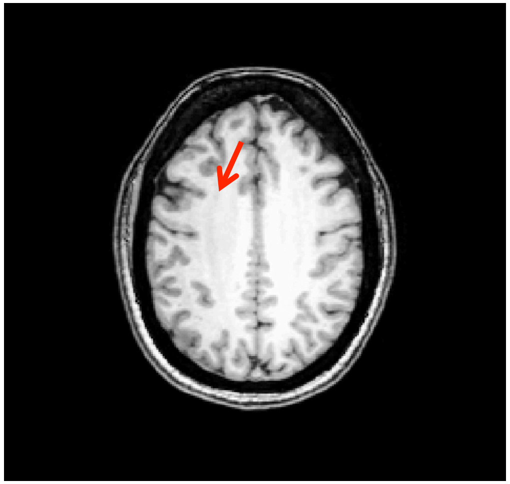
Severe: Ringing, Striping, Blurring extreme

What to look for: Any distortion in the scan image that can be described as a type of Ringing, Striping, and/or Blurring and is not a part of the head's anatomy. "Ringing/Striping" (light or dark circles, arcs, ripples, or bands in the image – organic shapes that often follow or mirror the curve of the head/brain); "Blurring" (the image appears smudged, smeared, or otherwise indistinct).

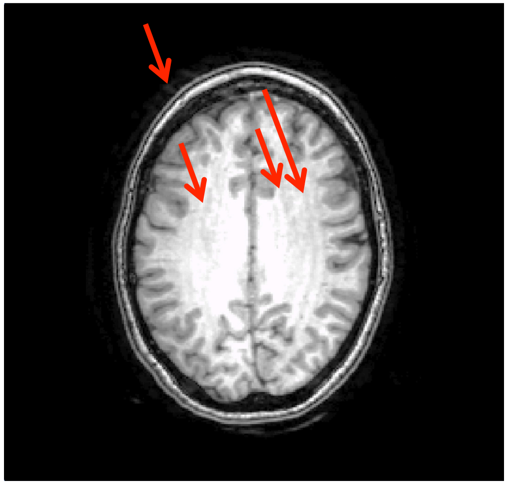
How to look for it: Scroll through all the slices in each view of the brain. Does the image appear crisp and clearly in focus at all points (no Blurring)? Do you see any unexpected arcs or bands, especially in the white matter around the ventricles (Shadowed Arc Artifact) or bordering the skull (Ringing)? Do you see circles resembling the ripples in a pond? If any of these or similar distortions are present, how visible are they?

What causes it: A variety of artifacts can be described as Ringing, Striping, or Blurring. Such artifacts have causes ranging from subject motion to MRI software or hardware issues. These diverse artifacts have been put into the same Ringing, Striping, Blurring category, because they are very often impossible to accurately distinguish from one another.

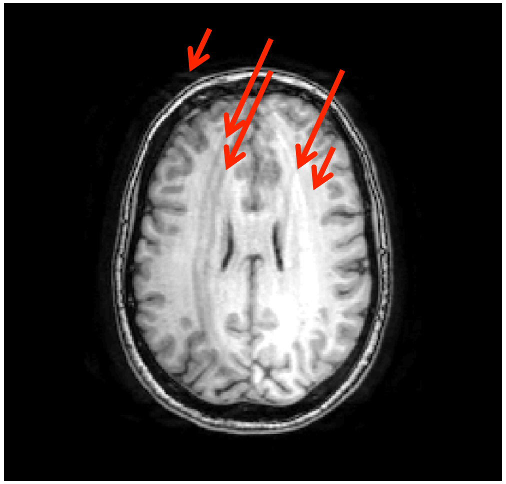
ANAT : Shadowed Arc Artifact



Mild: Shadowed Arc Artifact faintly detectable



Moderate: Shadowed Arc Artifact pronounced



Severe: Shadowed Arc Artifact extreme

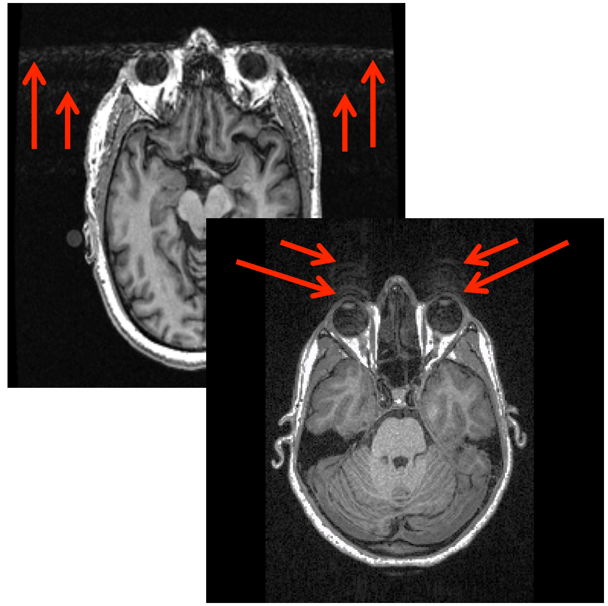
What to look for: Curved stripes ("shadowed arcs") through the white matter that follow the curve of the skull, sometimes extending outside the brain. Shadowed Arc Artifact should be rated in the "Ringing, Striping, Blurring" category.

How to look for it: Scroll through all the slices in each view of the brain. Shadowed Arcs are usually most clearly visible in the axial view white matter half way between the skull and midline. Do you see shadowed arcs? How dark are they?

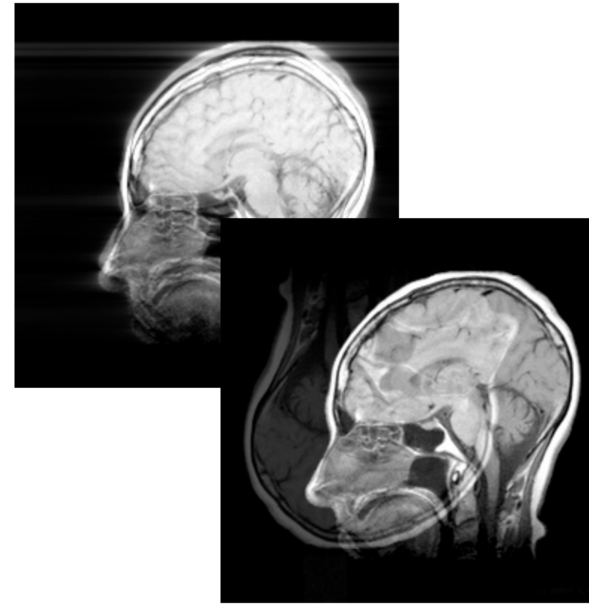
What causes it: "Shadowed Arc Artifact" can be caused by the image reconstruction from under-sampled data when parallel imaging techniques have been used to reduce the image acquisition time. If two-fold acceleration has been used, sometimes a faint outline of the head can be seen shifted by a half the FOV in the phase-encode direction (i.e. the "shadowed arc" in the white matter of the axial view in an anatomical scan). If higher levels of acceleration are used, additional artifacts may also be visible. The severity of this artifact depends on the sophistication of the scanner's image reconstruction method and so may vary significantly across scanner models and vendors.

ANAT : Ghosting

Mild: Ghosting faintly detectable



Moderate: Ghosting pronounced



Severe: Ghosting extreme

What to look for: A fainter displaced copy of the head, brain, or eyes, as though the original image were shifted and stamped again with less ink. The displaced "ghost(s)" can appear anywhere on the scan and will sometimes be upside down (called Quadrature Ghost Artifact). In some cases, the ghost will form a streak, like cartoon motion lines, and can be difficult to distinguish from "Striping" or "Blurring".

How to look for it: Ghosting is easier to see when you decrease the contrast between areas of high and low signal intensity by lowering the maximum brightness value while leaving the minimum brightness value at default (zero). Lower the max brightness to 1/3 of its default and scroll through all the slices and time points in each view of the brain. Ghosting is sometimes visible only in certain slices/time points (e.g. those with motion, or around eyes). Check in the black background first, do you see any shape that could be a fainter copy of the anatomy? Do you see streaks? How clearly visible are they? Can you still see them when you raise the max brightness back to default? Does the ghost image overlap the brain in the original image?

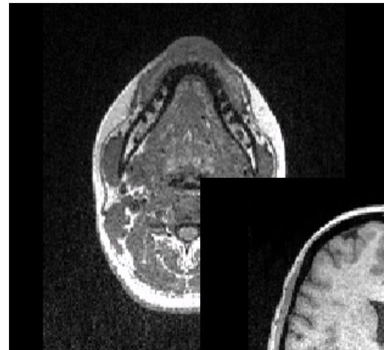
What causes it: Ghosting comes in several forms and has a variety of causes. One of the most common and avoidable causes is subject motion (imagine fainter copies of an image or streaks used to indicate motion in a comic). Quadrature Ghost Artifact is the result of a mismatch in the signal channels that causes signal to be shifted and mismapped upside down.

ANAT : Radio Frequency (RF) Noise (Severe = Spiking)

Normal Max Brightness

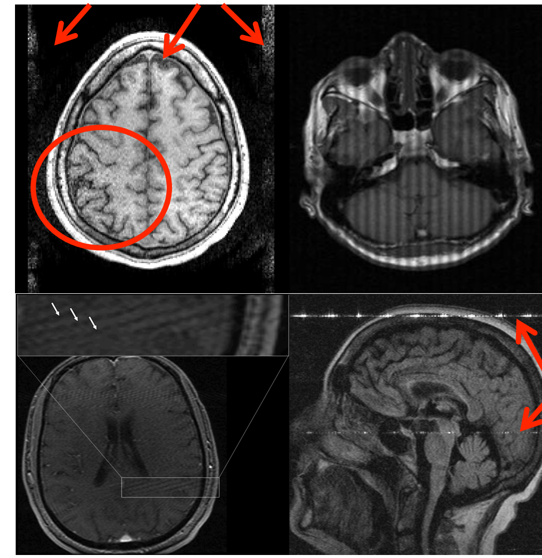
Lowered Max Brightness

Mild: Low-level RF noise that is visible only when lowering the maximum brightness value or is faintly visible without lowering the maximum brightness value.



Normal Max Brightness

Moderate: RF noise that is prominently visible without lowering the maximum brightness value.



Severe: Spiking is present – visible at default max brightness

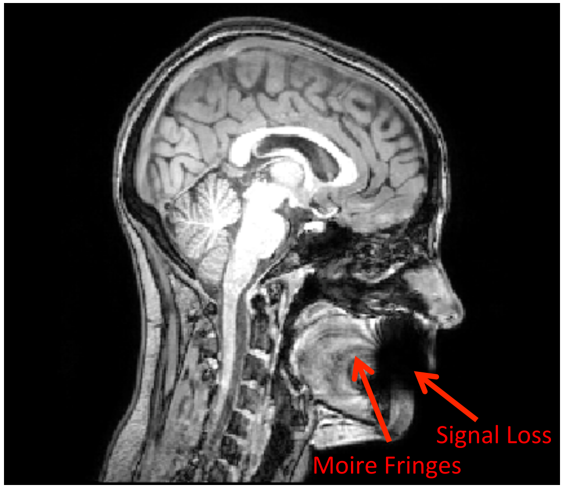
What to look for: Signal not caused by the subject's anatomy, resembling TV static over the brain image and/or in what should be a black background. Note: all MRI scans will have some low-level background thermal noise resulting from the electronic components in the RF coil and receiver hardware - familiarize yourself with the degree of thermal noise that is normal for your scanner. Severe RF noise (called "Spiking") looks like prominent uniform light and/or dark stripes, streaks, or a "zipper" across the image. Unlike "Ringing, Striping, Blurring", Spiking stripes are straight, rigid, and non-organic in shape, do not follow or mirror the curve of the head/brain, and often seem superimposed over the image.

How to look for it: Look for noise bands and spikes first by scrolling through all the slices and time points in each view of the brain. Noise bands and spikes will be prominently visible, but can selectively affect only a single slice or time point. If no spiking is present, look for moderate/mild RF Noise by lowering the maximum brightness value while leaving the minimum brightness at default (zero) and checking all slices again. Is there static in the background beyond what you would expect from this particular scanner? Is the static still visible when you raise the max brightness back to default?

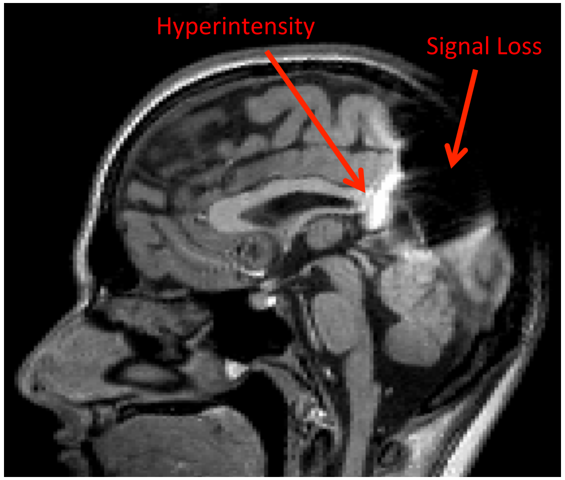
What causes it: RF Noise is caused by electrical signal interference during image acquisition. It can be a result of an outside signal entering the room (e.g. the door is left open or a cable from outside is not shielded or grounded), or it can come from electrical equipment inside the room if it is not adequately shielded. Another cause can be static electricity from bed clothing. Spiking results from electrical current in the gradient coils when conductive pathways are not perfect (e.g. a connector cable is fraying or loose).

ANAT : Susceptibility Artifact

None: Susceptibility Artifact not present



Outside Brain: Susceptibility Artifact present, but does not affect brain



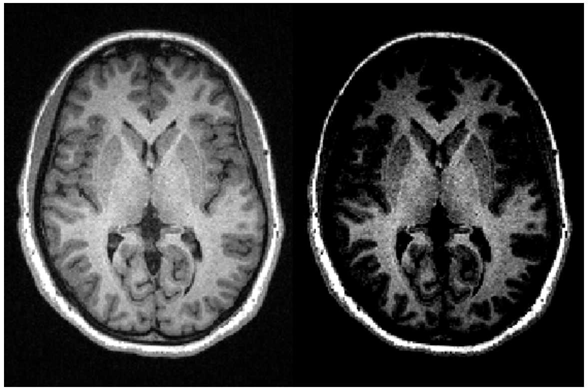
Affecting Brain: Susceptibility Artifact present and affects brain

What to look for: A black area, like a hole, inside the head that should not be there. The black hole will often be bordered by a bright band, an area of bright and dark ripples (called 'Moire Fringes'), and/or other distortions in the surrounding anatomy.

How to look for it: Scroll through all the slices in each view of the brain. Is there a black hole in the head that should not be there? Is the black hole in the brain? Do any of the distortions around the black hole (e.g. Moire Fringes) go into the brain?

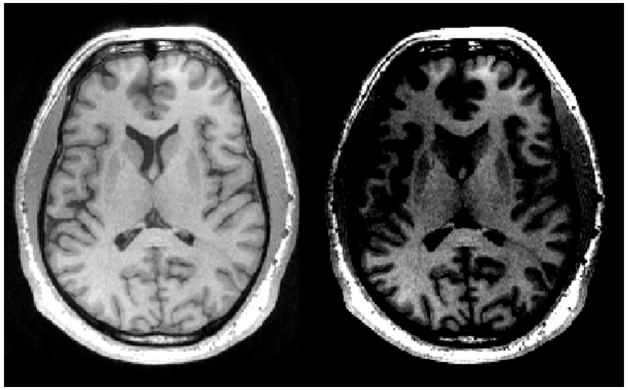
What causes it: A common cause is metal in or near the scanner, like the two above examples: dental work (middle) and a metal hairclip (right). Different substances (e.g. metal vs. bone) can be magnetized to different degrees (their magnetic susceptibility is different) and when they are right next to each other in the scanner the uniform magnetic field the MRI needs to create an accurate image is irreparably distorted making the image too dark (signal loss) and/or too bright (hyperintensity). Most metals, whether they are ferromagnetic or not, can shield the nearby area from the RF signal transmitted by the scanner, meaning there is no MRI signal in that area to detect.

ANAT : Unexpected Inhomogeneity



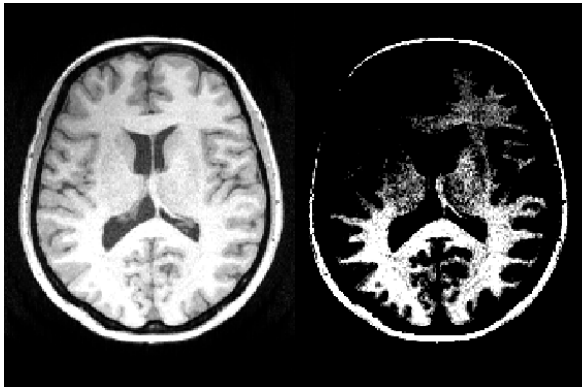
Normal Contrast *High Contrast*

None: signal intensity uniform throughout image



Normal Contrast *High Contrast*

Expected: inconsistent signal intensity fits coil profile



Normal Contrast *High Contrast*

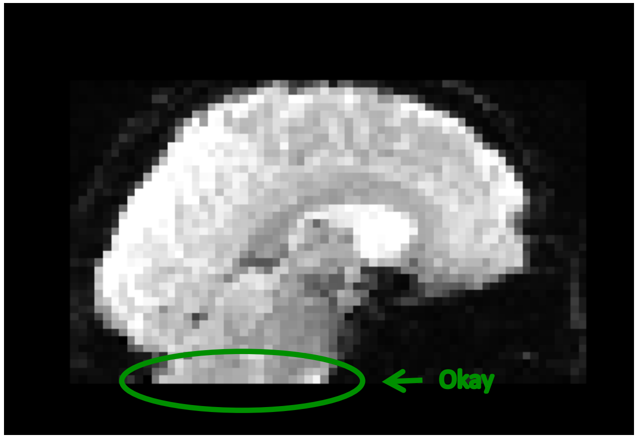
Unexpected: inconsistent signal intensity does not fit coil profile

What to look for: An inconsistency/asymmetry in the signal intensity that makes the brain image appear too bright in some areas and/or too dark in others. Signal homogeneity varies notably between receiver coils. Most coils' signal is slightly inhomogeneous in a reliable way (e.g. always brighter at the front and back of the brain). Signal inhomogeneity is concerning only when it is severe and/or does not match the expected coil profile.

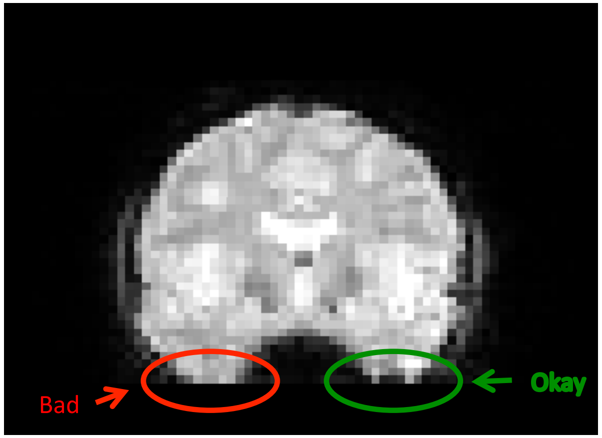
How to look for it: *S*ignal inhomogeneity is easier to see when you increase the contrast between areas of high and low signal intensity by raising the minimum brightness value while leaving the maximum brightness value at default. Raise the minimum brightness to 1/3, then 1/2, then 2/3 of the maximum, each time scrolling through all the slices in each view of the brain. It is normal for the outer rim of the brain to be brighter than the interior, but this pattern should be symmetrical, the font should mirror the back and the left should mirror the right. Is the front of the brain brighter than the back or the left brighter than the right? How big is the difference? Does it fit the signature pattern of the receiver coil you are working with?

What causes it: MRI's use a receiver coil to pick up the radio frequency signal used to map the image. If the receiver coil is not uniformly sensitive, it incorrectly reads the signal as stronger in some areas (making the image brighter), and weaker in others (making the image darker). Modern MRI systems use receiver coils made up of arrays of small coils - 8, 12, 32 or more. There is an intentional degree of unevenness in their sensitivity and so the scanner will always read the signal with the same slightly inhomogeneous pattern. If the inhomogeneity is much greater than usual, it might indicate some part of the receiver coil array is not working (e.g. one of the coil plugs was not plugged in correctly, or the electronics for some of the small coils in the array have failed), in this case the coil would need repair or replacement.

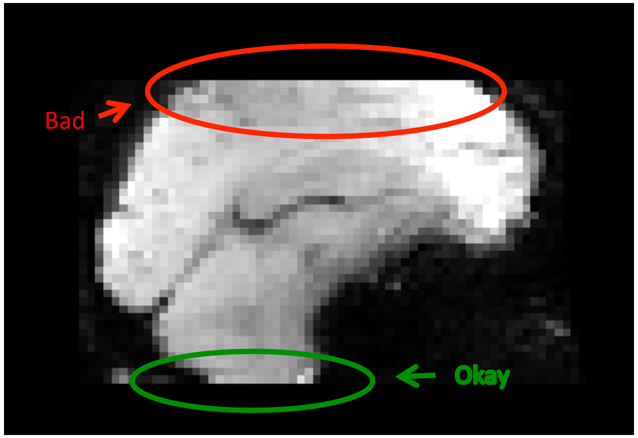
BOLD : Head Coverage



Good: EMBARC brain target area fully covered in FOV.



Questionable: FOV clips slice(s) of EMBARC brain target area.



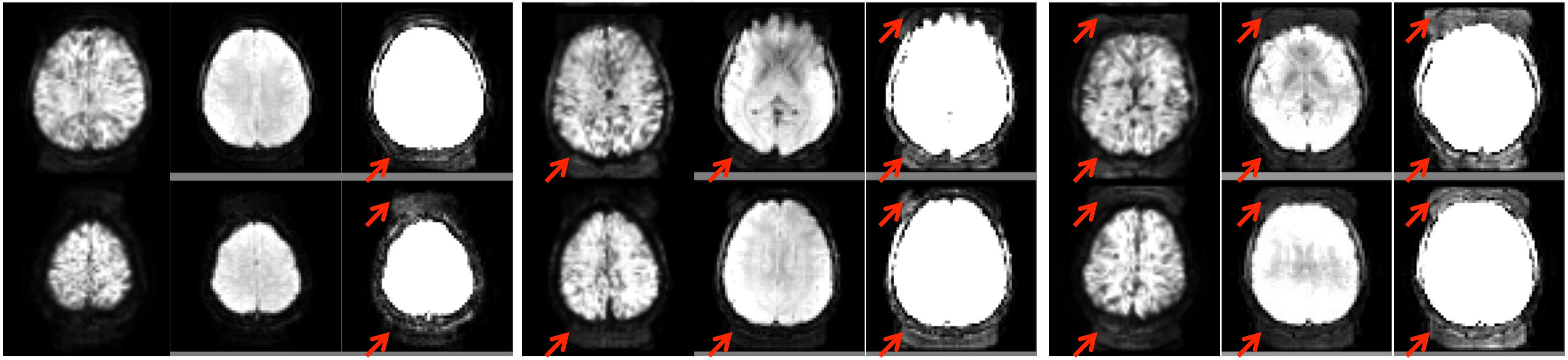
Bad: FOV clips significant portion of EMBARC target area

What to look for: Perfect head coverage means the entire brain target area (the part of the brain you care about in your study) is clearly visible in the scan's field of view (FOV), ideally with at least one slice of black background buffer on each side. For EMBARC, the brain target area runs from the top of the brain to the bottom of the temporal lobes, and does not include the cerebellum. Note: if a subject's brain is just too large to fit in the scan's FOV, the FOV frame should be centered over the brain target area and should clip the extra slice from the *top* of the brain (*not* the temporal lobes) if the number of slices that must be clipped is odd.

How to look for it: Scroll through all the slices in each view of the brain. Is there any place where the brain's natural curve becomes suddenly flat as if clipped off by the black background? Is the clipped piece part of your brain target area? How much of the brain target area is clipped, only a few slices or a much larger section? Remember you will need to scroll through all the slices in the coronal (front/back) view of the brain to check if the full temporal lobe is covered since the bottom tips are not visible in all slices.

What causes it: The person operating the scanner positions the frame of MRI FOV by hand. Poor head coverage is usually caused by the scanner operator failing to reposition the FOV if a part of the brain target area is being cut off. Occasionally, the subject will cause the head coverage loss by moving out if the FOV.

BOLD : Ghosting



SNR Map | *Mean Intensity Map* | *Mean Intensity (lowered max. brightness)* | *SNR Map* | *Mean Intensity Map* | *Mean Intensity (lowered max. brightness)* | *SNR Map* | *Mean Intensity Map* | *Mean Intensity (lowered max. brightness)*

Mild: Ghosting faintly detectable in Mean Intensity Map only when max brightness is lowered

Moderate: Ghosting notably visible in SNR map and Mean Intensity Map at default max brightness and prominently visible at lowered max brightness

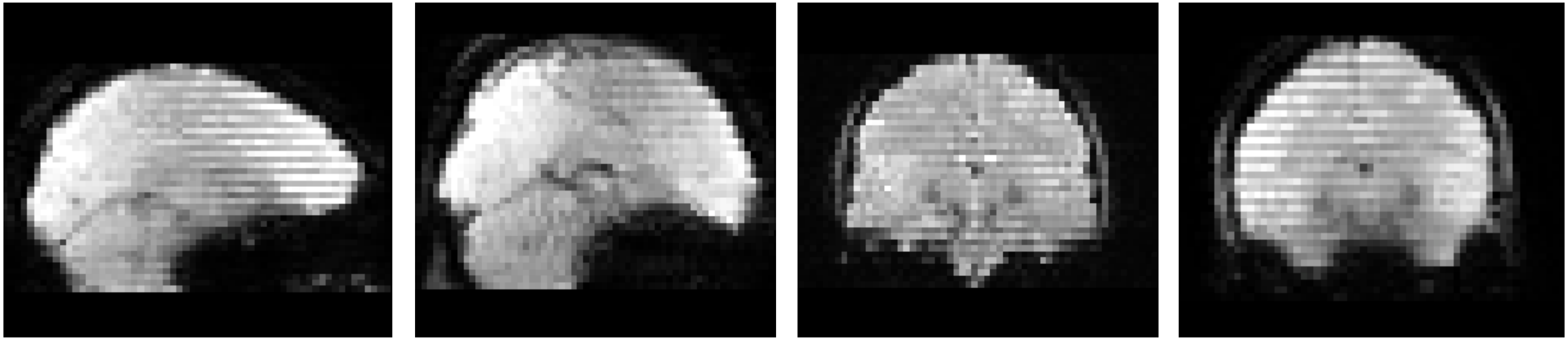
Severe: Ghosting prominently visible in SNR map and Mean Intensity Map at default max brightness and extreme visible at lowered max brightness

What to look for: A fainter displaced copy of the brain as though the original image were shifted and stamped again with less ink. In BOLD scans, the "ghost" brain may look like a blob or smudge and is usually seen directly above and/or below the original brain image in a conventional axial view. However, the location is determined by scanner acquisition settings, so it may appear elsewhere if the image is acquired in a different view (e.g. coronal). Note: like background noise, all BOLD scans will contain a faint ghost. We are concerned with ghosts that are not faint, or vary across time points or slices.

How to look for it: Ghosting is easier to see when you decrease the contrast between areas of high and low signal intensity by lowering the maximum brightness value while leaving the minimum brightness value at default (zero). Lower the max to 1/3 of its default and scroll through all slices and time points in each view of the brain. Ghosting is sometimes visible only in certain slices/time points (e.g. those with motion). Now examine the SNR map. In both maps, check the black background first, do you see a blob or smudge directly above and/or below the brain? How clearly visible is it? Do you still see it when you raise the max back to default? Does the arc of the ghost brain overlap the original brain?

What causes it: Ghosting comes in several forms and has a variety of causes. One of the most common and avoidable causes is subject motion (imagine fainter copies of an object or streaks used to indicate motion in a comic, these are variable or intermittent ghosts). Non-uniform ghosts may indicate a problem with the receiver coil, or the image reconstruction.

BOLD : Motion Slice Artifact

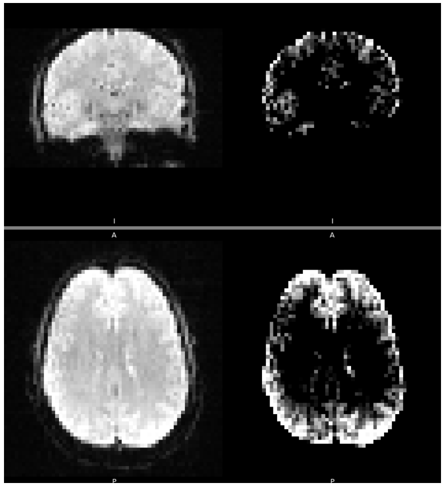


What to look for: Rigid, uniform stripes running horizontally across the brain like Venetian blinds.

How to look for it: Motion Slice Artifact occurs only when the subject moves during a scan and so will only be visible in certain time points. Scroll through all the time points. At any point when the brain shifts, rocks, or tilts, do you see a flash of horizontal stripes? Motion slice artifact is visible in the sagittal and coronal views for images acquired in the conventional axial plane, but may appear in the axial view if the images were acquired in one of the other planes.

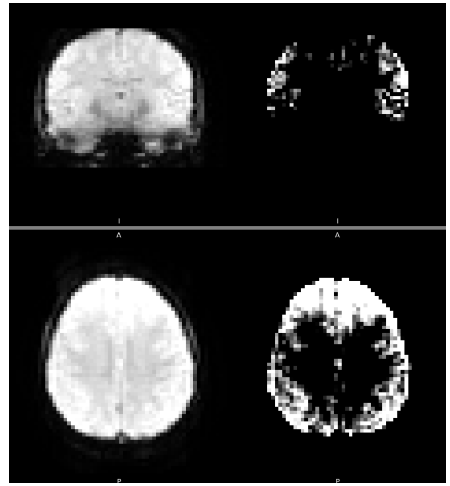
What causes it: One way MRI scanners can be set to produce a BOLD scan is by collecting the odd numbered brain slices and then going back and collecting the even numbered brain slices (called “interleaved acquisition”). If the subject moves between the time the scanner collects the odd slices and the even slices, the slices do not line up correctly (some slices in the brain are acquired twice, some not at all). This positional displacement and variation in signal intensity from slices acquired twice results in the Motion Slice Artifact when the scanner tries to display the whole brain image in a view perpendicular to the separate slices.

BOLD : Signal Inhomogeneity



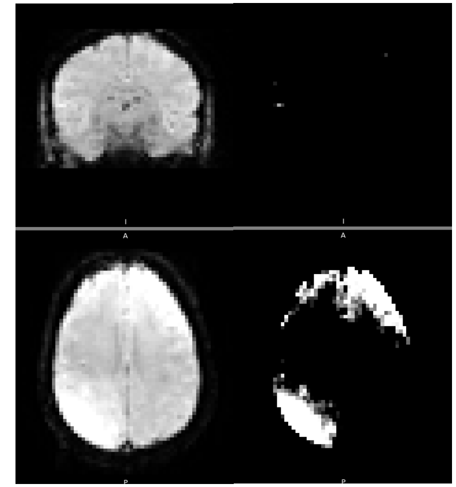
Normal Contrast *High Contrast*

None: signal intensity uniform throughout image



Normal Contrast *High Contrast*

Expected: inconsistent signal intensity fits scanner/coil profile



Normal Contrast *High Contrast*

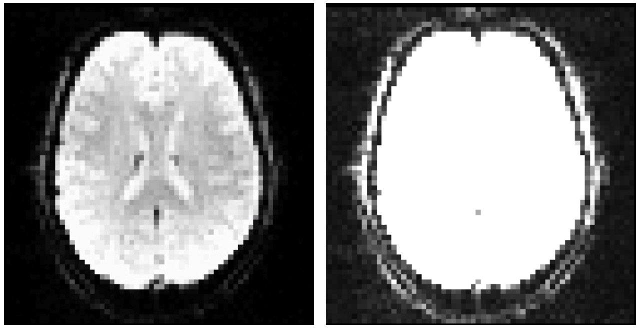
Unexpected: inconsistent signal intensity does not fit scanner/ coil profile

What to look for: An inconsistency/asymmetry in the signal intensity that makes the brain image appear too bright in some areas and/or too dark in others. Signal homogeneity varies notably between receiver coils. Most coils' signal is slightly inhomogeneous in a reliable way (e.g. always brighter at the front and back of the brain). Signal inhomogeneity is concerning only when it is severe and/or does not match the expected coil profile.

How to look for it: *S*ignal inhomogeneity is easier to see when you increase the contrast between areas of high and low signal intensity by raising the minimum brightness value while leaving the maximum brightness value at default. Raise the minimum brightness to 1/3, then 1/2, then 2/3 of the maximum, each time scrolling through all the slices in each view of the brain. It is normal for the outer rim of the brain to be brighter than the interior, but this pattern should be symmetrical, the font should mirror the back and the left should mirror the right. Is the front of the brain brighter than the back or the left brighter than the right? How big is the difference? Does it fit the signature pattern of the receiver coil you are working with?

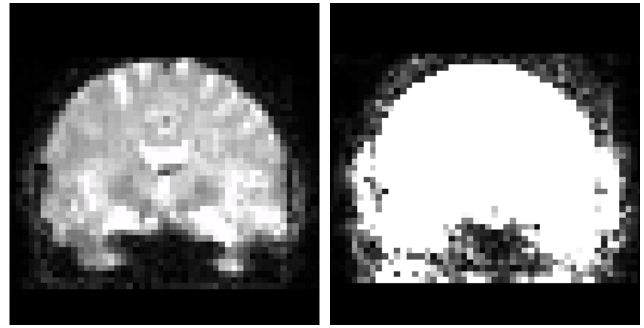
What causes it: MRI's use a receiver coil to pick up the radio frequency signal used to map the image. If the receiver coil is not uniformly sensitive, it incorrectly reads the signal as stronger in some areas (making the image brighter), and weaker in others (making the image darker). Modern MRI systems use receiver coils made up of arrays of small coils - 8, 12, 32 or more. There is an intentional degree of unevenness in their sensitivity and so the scanner will always read the signal with the same slightly inhomogeneous pattern. If the inhomogeneity is much greater than usual, it might indicate some part of the receiver coil array is not working (e.g. one of the coil plugs was not plugged in correctly, or the electronics for some of the small coils in the array have failed), in this case the coil would need repair or replacement.

BOLD : Radio Frequency (RF) Noise (Severe = Spiking)



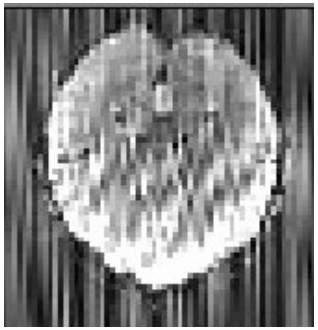
Normal Max Brightness *Lowered Max Brightness*

Mild: Low-level RF noise/static faintly visible at default max brightness or visible only when max brightness lowered



Normal Max Brightness *Lowered Max Brightness*

Moderate: RF noise/static notably visible at default max brightness and pronounced when max brightness lowered



Normal Max Brightness

Severe: Spiking present – extreme at default max brightness

What to look for: Signal not caused by the subject's anatomy, resembling TV static over the brain image and/or in what should be a black background. Note: all MRI scans will have some low-level background thermal noise resulting from the electronic components in the RF coil and receiver hardware - familiarize yourself with the degree of thermal noise that is normal for your scanner. Severe RF noise (called "Spiking") looks like prominent uniform light and/or dark stripes, streaks, or a "zipper" across the image. Unlike "Ringing, Striping, Blurring", Spiking stripes are straight, rigid, and non-organic in shape, do not follow or mirror the curve of the head/brain, and often seem superimposed over the image.

How to look for it: Look for noise bands and spikes first by scrolling through all the slices and time points in each view of the brain. Noise bands and spikes will be prominently visible, but can selectively affect only a single slice or time point. If no spiking is present, look for moderate/mild RF Noise by lowering the maximum brightness value while leaving the minimum brightness value at default (zero) and checking all slices again. Is there static in the background beyond what you would expect from this particular scanner? How visible is the static when you raise the max brightness to default?

What causes it: RF Noise is caused by electrical signal interference during image acquisition. It can be a result of an outside signal entering the room (e.g. the door is left open or a cable from outside is not shielded or grounded), or it can come from electrical equipment inside the room if it is not adequately shielded. In BOLD fMRI experiments, electrical response buttons used by the subject could be a potential contributor of such noise - this will be apparent in only a small number of slices in each time point, but different slices in different time points. Another cause can be static electricity from bed clothing. Spiking results from electrical current in the gradient coils when conductive pathways are not perfect (e.g. a connector cable is fraying or loose). BOLD scans are particularly susceptible to this effect as the gradients are switched so rapidly with such large currents for long periods of time.

Acknowledgements

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