MRC Cognition and Brain Sciences Unit

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# TMS-fMRI artifacts: Avoidance and rejection

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# Overview

What is an artifact?

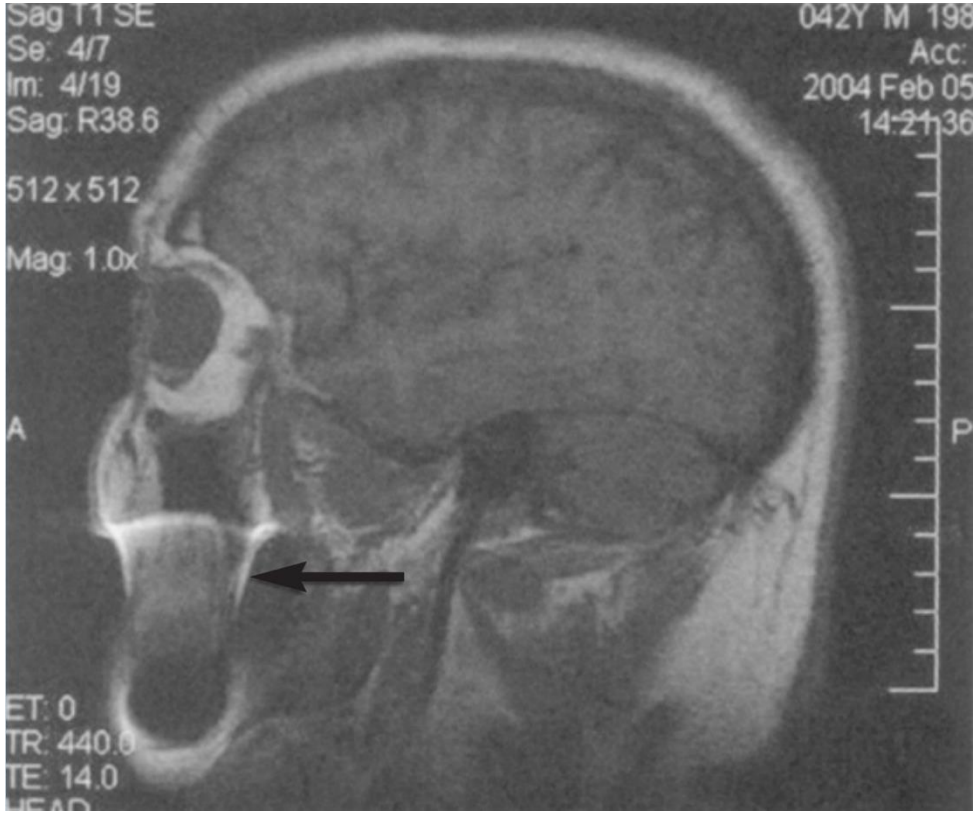
TMS artifacts

Three approaches to deal with artifacts

1. remove affected data
2a. deliver in gap between volumes
2b. deliver in gap between slices (interslice)
    -protocol
    -demonstration

# What is an artifact?

- An artefact is a feature in an image not present in the original object
- An anomaly can be seen during visual representation of the MR data






Erasmus et al., 2004. *SA Journal of Radiology.*

# TMS artifacts

- TMS creates several artifacts in scanner environment falling under categories:

- Static artifacts
  arise through presence of the TMS setup itself

- Dynamic artifacts
  due to operating the TMS setup

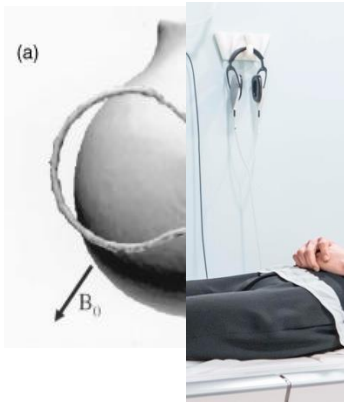
# TMS artifacts: coil

- Static: magnetic susceptibility

  -sequence you use
  -distance TMS coil to the head

- Dynamic: motion

  -modern coil holders
  -keeping participants head steady






Baudewig et al,. (2000), *MRI*

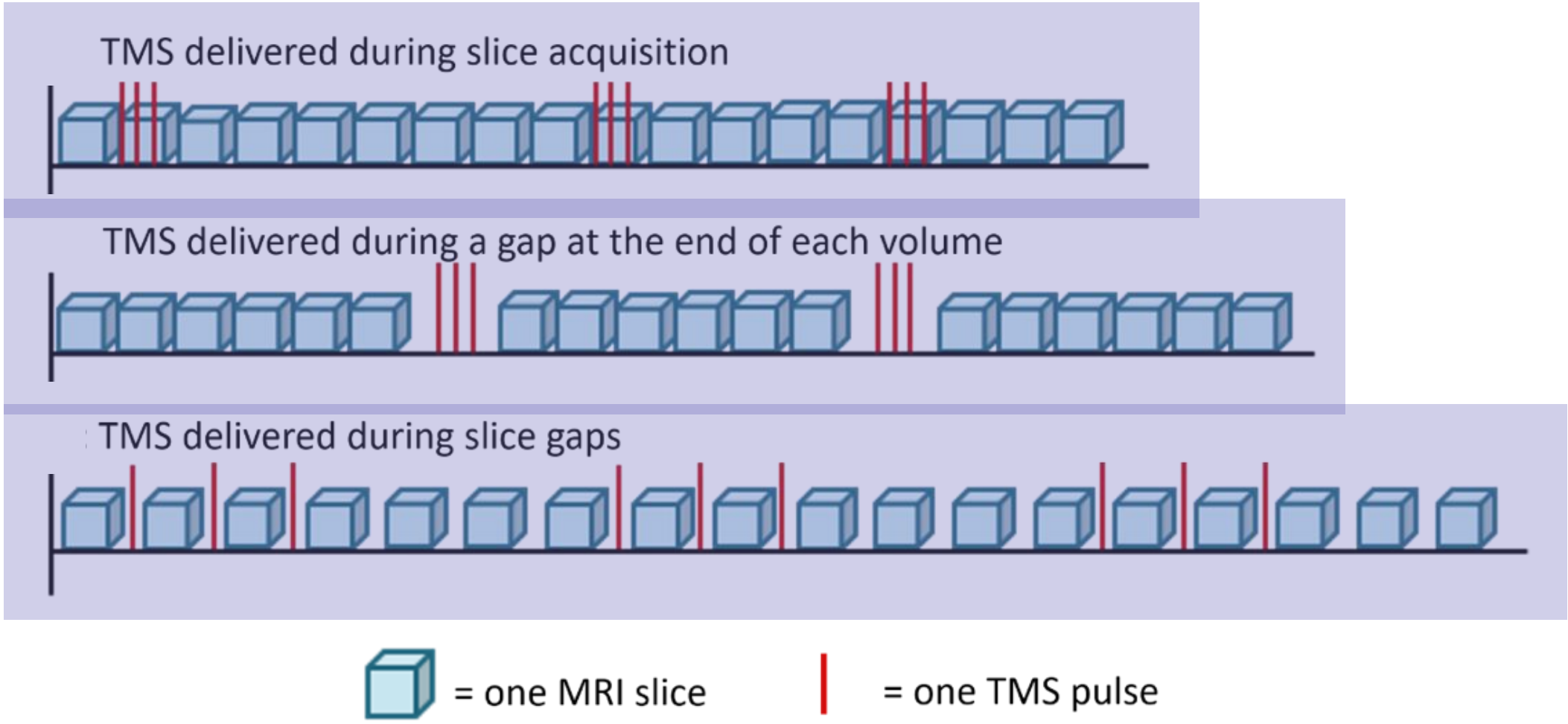
# TMS artifacts: Pulses

- TMS pulse = brief, intense magnetic fields over a participant's scalp
- Applying this large, time varying magnetic field from a TMS coil can perturb the imaging magnetic fields
- The size of distortion will depend on several factors e.g., TMS coil orientation, and TMS pulse intensity

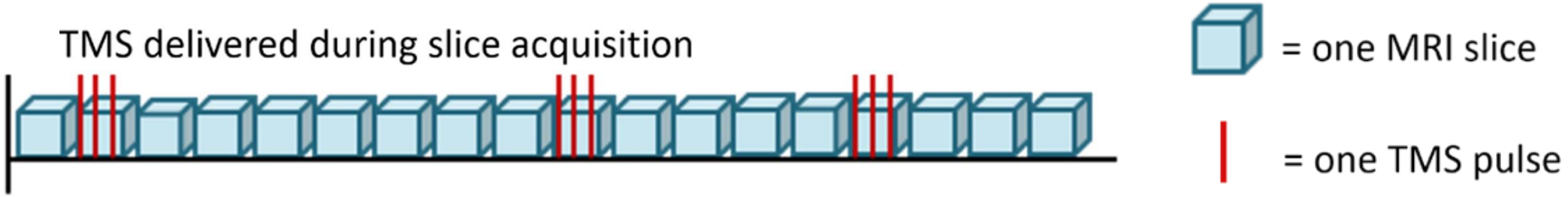


Riddle et al., (2022) *FiHN*

# Approaches to deal with artifacts



# 1: Remove affected data




**Temporal interpolation**
replace each TMS-slice with average of same slice in preceding and subsequent volume

**Advantages**
high flexibility, can stimulate at any time

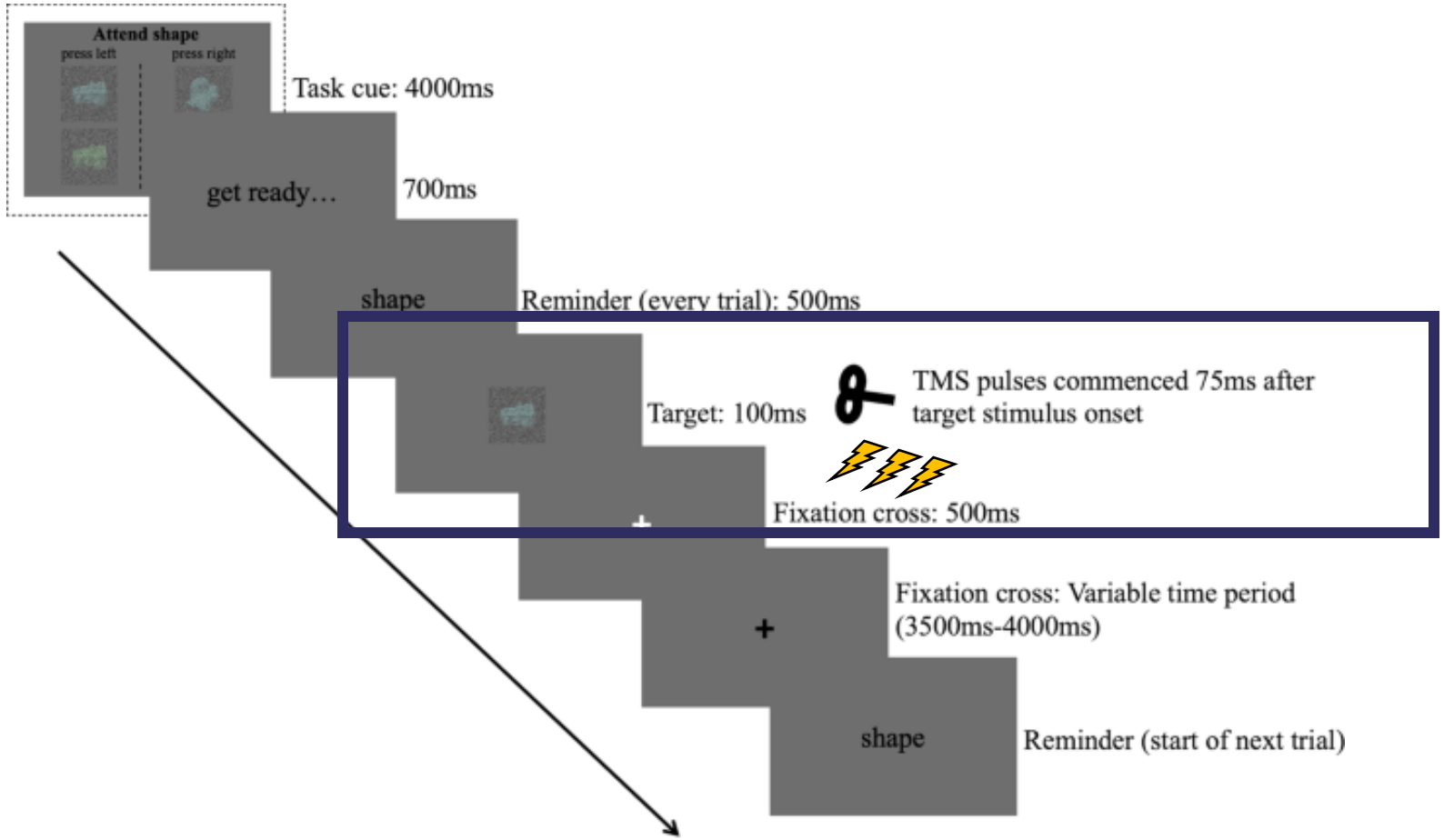
**Disadvantages**
lose temporal resolution
laborious and requires careful assessment to ensure that all affected slices have been removed



Feredoes et al., (2011), *PNAS;* Jackson et al., (2021), *Comms Bio*

# Example study: Remove affected data

- Experiment looking at causal role of PFC in selective-attention
- Requires TMS pulses online in scanner while participants are paying attention to different features of objects

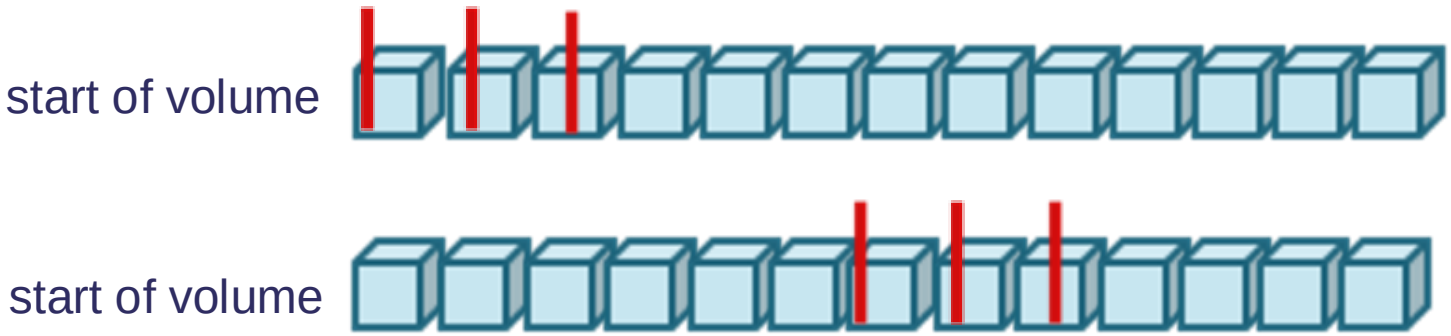





Jackson et al., (2021), *Comms Bio*

# Example study: Remove affected data

- 13 Hz TMS protocol (disruptive, ~76.9ms between pulses)
- TR = 2080, 35 slices = 59.4 ms per slice

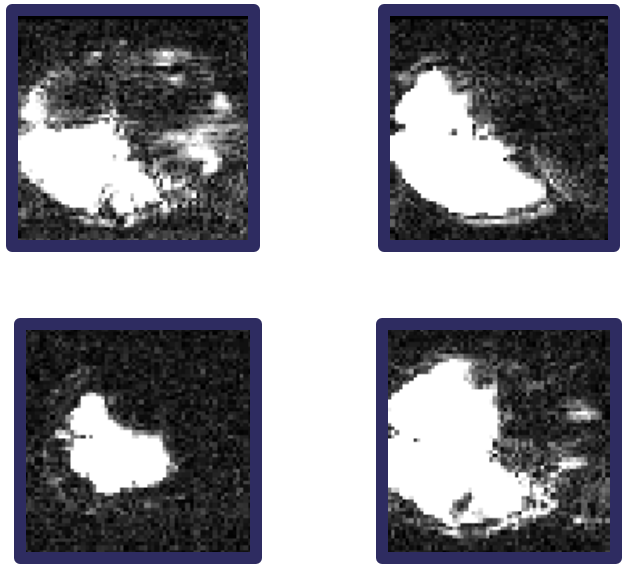





Jackson et al., (2021), *Comms Bio*

# Example study: Remove affected data

- Slices that had a signal magnitude > 1.5 SD from run mean (prior to preprocessing)
- Visual inspection for presence of artefact



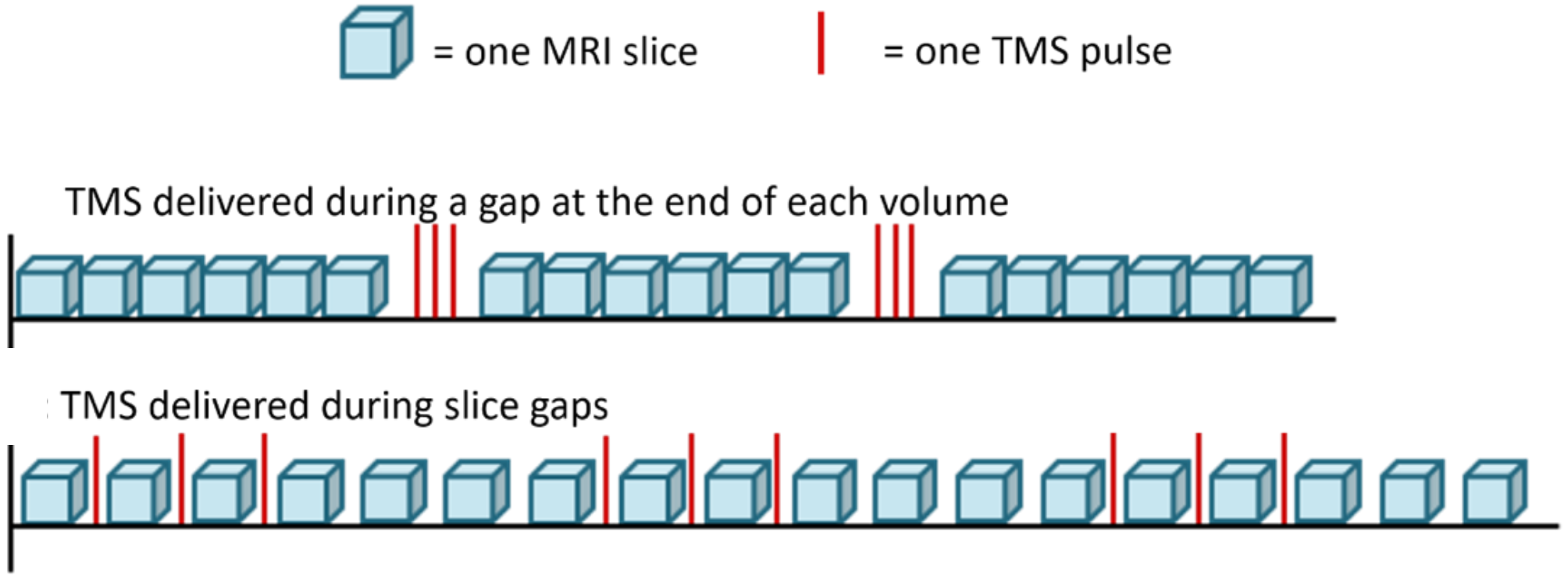
## Problems

- Visual inspection tricky for certain slices (near top/based head)
- Extra slice sometimes affected due to no temporal gaps

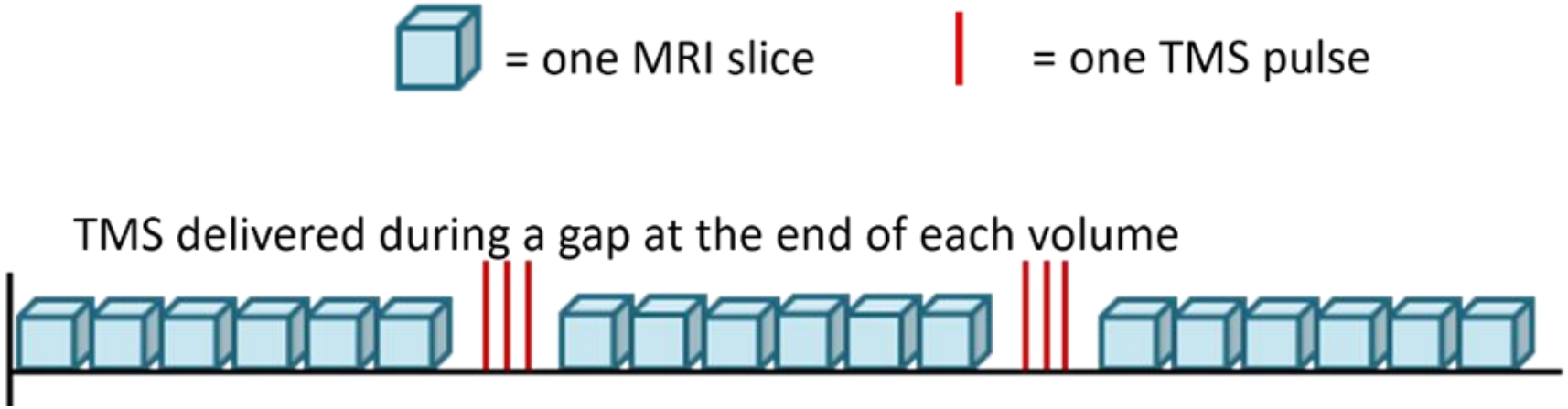


Jackson et al., (2021), *Comms Bio*

# Delivering the pulse during gaps



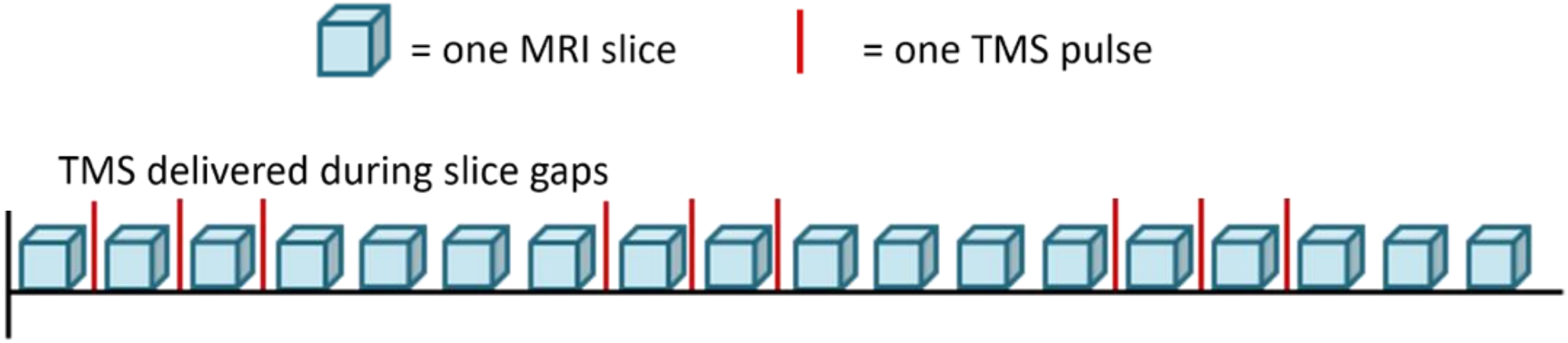
# 2: Gaps in TR




**Advantages**
No EPI slices are sacrificed. Avoid intense processing steps.

**Disadvantages**
Protocol needs to be longer to include gaps. TMS and MR volume onsets cannot be jittered.

# 3: Gaps during slices (interslice)

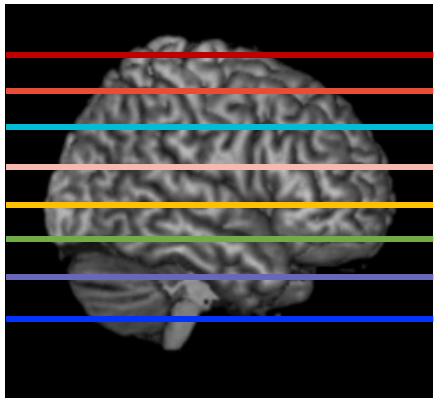



**Advantage**
Avoids data loss, more experimental flexibility

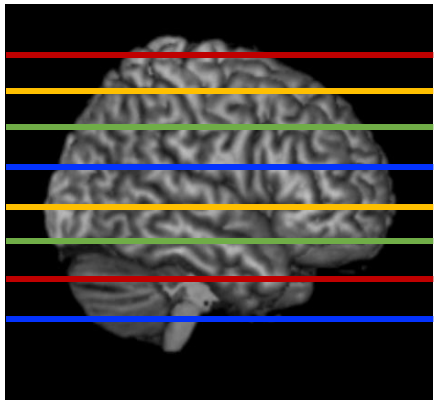
**Disadvantage**
Limit to the TMS protocols that can be achieved. Reliable hardware and software are essential as the pulses must be controlled precisely. Extensive piloting required.

# Protocol design

- Aimed to develop a fast repetitive TMS protocol
- Tested protocol on a spherical phantom
- Multiband EPI sequence



one slice at a time



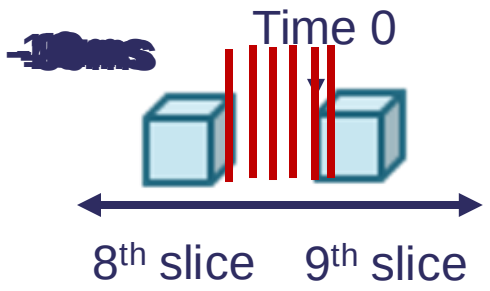
multiple slices at a time (multiband)

- 37.5ms slice gap. Slice (62.5ms) + gap = 100ms, allowing 10Hz protocol

# Protocol design

**Conditions of interest**

- Time from slice onset (10ms intervals)
- TMS amplitude (20, 40, 100% MSO)
- Number of TMS pulses (1, 3)




**Timing control**

- read in scanner signal at every slice onset -> count number of slices -> send trigger to stimulator

# Analysis

## Temporal signal to noise ratio (tSNR)

- Provides information on the data quality of fMRI time series

- Estimates noise over time

tSNR = mean/stdev of times series (**high is good**)

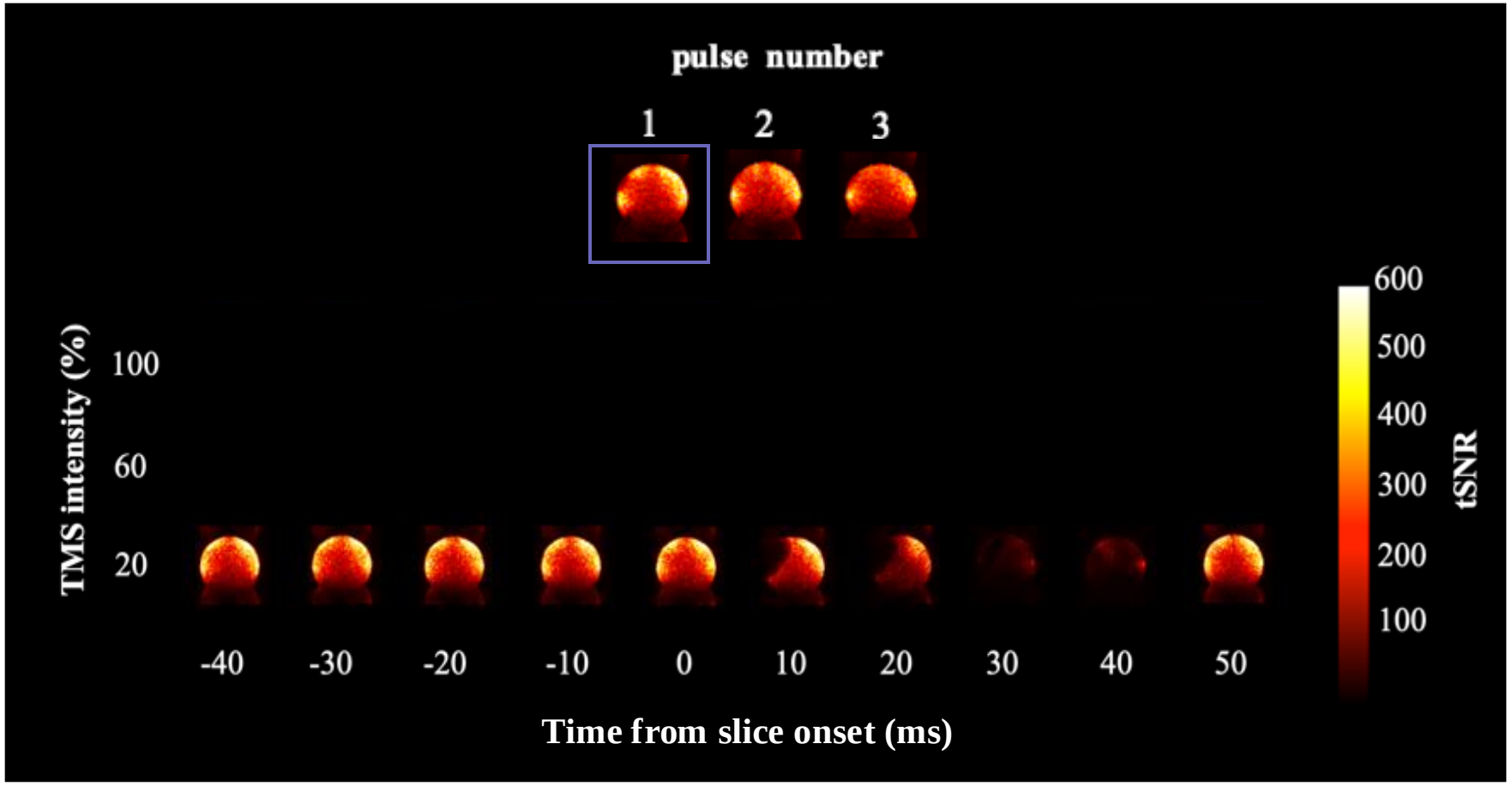
- Created tSNR maps for each conditions for each slice of interest

e.g., 1 condition =




100% MSO

# Results



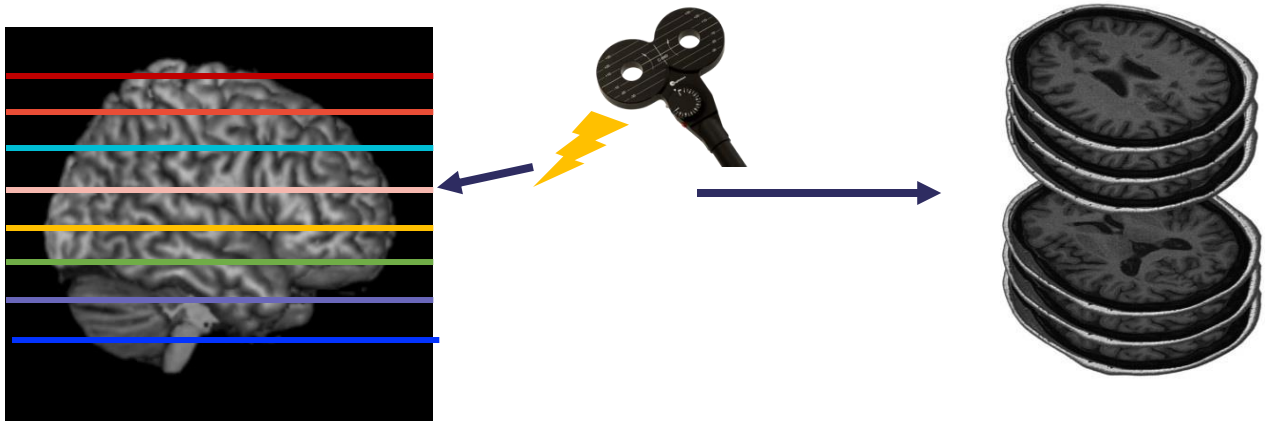



Scrivener et al., (2021), *BioRxiv*

# Demonstration

**Calculate tSNR (average signal over standard deviation throughout time)**

1. Use FSL functions to split fMRI volumes into individual slices (**fslslice**)



10 volumes in our case

2. Create merged image with slice of interest over volumes (**fslmerge**)

# Demonstration

**Calculate tSNR (average signal over standard deviation throughout time)**

3. Calculate mean, standard deviation and tSNR over the number of volumes (10) (**fslmaths**)

4. View tSNR maps on mricron/fsl

**Data, code & instructions for creating tSNR maps** → **https://osf.io/tf5wj/**

# Conclusions

- Three main approaches for dealing with TMS artefacts
- Weigh up pros and cons of using different methods
- Important to test own experimental setup with own equipment
- Demonstration of how to create tSNR maps

# References


- Baudewig, J., Paulus, W., & Frahm, J. (2000). Artifacts caused by transcranial magnetic stimulation coils and EEG electrodes in T2∗-weighted echo-planar imaging. Magnetic resonance imaging, 18(4), 479-484.
- Erasmus, L. J., Hurter, D., Naudé, M., Kritzinger, H. G., & Acho, S. (2004). A short overview of MRI artefacts. SA Journal of Radiology, 8(2).
- Feredoes, E., Heinen, K., Weiskopf, N., Ruff, C., & Driver, J. (2011). Causal evidence for frontal involvement in memory target maintenance by posterior brain areas during distracter interference of visual working memory. Proceedings of the National Academy of Sciences, 108(42), 17510-17515.
- Jackson, J. B., Feredoes, E., Rich, A. N., Lindner, M., & Woolgar, A. (2021). Concurrent neuroimaging and neurostimulation reveals a causal role for dlPFC in coding of task-relevant information. Communications biology, 4(1), 588.
- **Riddle, J., Scimeca, J. M., Pagnotta, M. F., Inglis, B., Sheltraw, D., Muse-Fisher, C., & D'Esposito, M. (2022). A guide for concurrent TMS-fMRI to investigate functional brain networks. Frontiers in Human Neuroscience, 16, 1050605.**
- Scrivener, C. L., Jackson, J. B., Correia, M. M., Mada, M., & Woolgar, A. (2021). Now you see it, now you don't: optimal parameters for interslice stimulation in concurrent TMS-fMRI. bioRxiv, 2021-05.

# Readings


- Bergmann, T. O., Varatheeswaran, R., Hanlon, C. A., Madsen, K. H., Thielscher, A., & Siebner, H. R. (2021). Concurrent TMS-fMRI for causal network perturbation and proof of target engagement. Neuroimage, 237, 118093.

- Bestmann, S., Baudewig, J., & Frahm, J. (2003). On the synchronization of transcranial magnetic stimulation and functional echo-planar imaging. Journal of Magnetic Resonance Imaging: An Official Journal of the International Society for Magnetic Resonance in Medicine, 17(3), 309-316.

- Mizutani-Tiebel, Y., Tik, M., Chang, K. Y., Padberg, F., Soldini, A., Wilkinson, Z., ... & Keeser, D. (2022). Concurrent TMS-fMRI: technical challenges, developments, and overview of previous studies. Frontiers in Psychiatry, 13, 825205.

- Woolgar, A., Feredoes, E., Assem, M., Bassil, Y., Bergmann, T. O., Beynel, L., ... & Sack, A. (2024). Concurrent TMS-fMRI: An international consensus and functional guide for current and future researchers.

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