Inconsistent MR Acquisition in Longitudinal Volumetric Analysis: Impacts and Solutions

Lianrui Zuo[1,5], Savannah P. Hays[1], Blake E. Dewey[3], Samuel W. Remedios[2,6], Yuan Xue[1], Sandra D. Cassard[3], Carolyn Koch[3], Ann Fishman[4], Aaron Carass[1], Jerry L. Prince[1], Ellen M. Mowry[3], Scott D. Newsome[3]

[1]*Department of Electrical & Computer Engineering,* [2]*Department of Computer Science, The Johns Hopkins University, Baltimore, MD, USA*
[3]*Department of Neurology,* [4]*Geriatric Psychiatry and Neuropsychiatry, Johns Hopkins School of Medicine, Baltimore, MD, USA*
[5]*National Institute on Aging,* [6]*Radiology and Imaging Sciences, National Institutes of Health, Bethesda, MD, USA*

1. BACKGROUND

- **MRI** plays an important role in **studying MS**:

Diagnosis | Monitor disease progress | Clinical research

- MRI **lacks consistency** in acquisition:

Scanner hardware & software | Acquisition parameters | Site-specific preference | Technician's expertise

- A hard choice in MRI: Consistency **OR** Sample size
- Is it possible? Consistency **AND** Sample size

2. OBJECTIVES

- Investigate the impact of **inconsistent MR acquisition** in **multi-site longitudinal volumetric analysis** for people with MS
- Investigate **image harmonization** as a potential solution

3. DATASETS

- Traditional vs Early Aggressive Therapy for MS (**TREAT-MS**) trial[1-2]
- Acquisition guidelines based on CMSC2018, but **not mandated**
- **Longitudinal** data: baseline, month 6, 12, 24, 36, 48
- **Data** in this study: subset of TREAT-MS

×8 Imaging sites | ×209 People with MS | ×549 3D high-res T1w

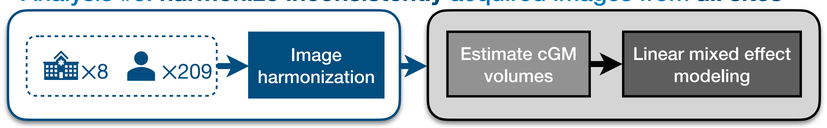
4. METHODS

- Task: study statistical relationship **cortical gray matter (cGM) volumes** & **age**
- Processing steps: estimate cGM volume, linear mixed effect modeling
- Three parallel analyses: different **sample sizes** & **acquisition consistency**

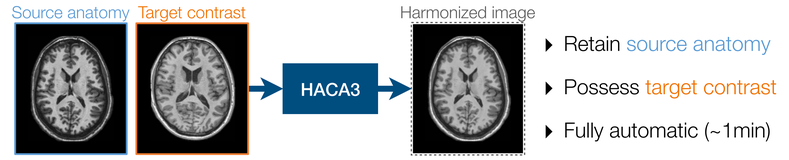
Analysis #1: **consistently** acquired images from a **single site**

Analysis #2: **inconsistently** acquired images from **all sites**

Analysis #3: **harmonize inconsistently** acquired images from **all sites**

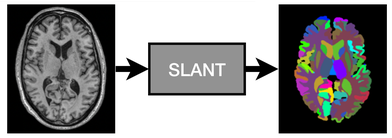


- **Image harmonization** using **HACA3**[3]



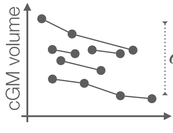
- Retain source anatomy
- Possess target contrast
- Fully automatic (~1min)

- **Estimate cGM volumes** using **SLANT**[4]



- Input: T1w MR image
- Output: labels of 132 structures
- Fully automatic (~3min runtime)

- **Linear mixed effect modeling** between cGM volumes & age



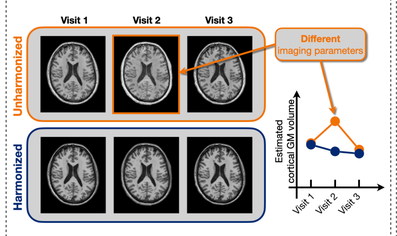
σ_O^2 Overall variance = σ_P^2 Population variance + σ_e^2 Residual variance

Prefer high **ICC** (Longitudinal intra-class correlation) $\text{ICC} = \frac{\sigma_P^2}{\sigma_P^2 + \sigma_e^2}$

Prefer low **RV** (Residual variance) $\text{RV} = \sigma_e^2$

5. RESULTS & CONCLUSIONS

- A sneak peek of **one case**



- **Statistical analysis**

	Scenario	ICC (Larger is better. Max=1)	RV (Lower is better. Min=0)
Analysis #1 (×1, ×83)	✓ Consistent acquisition ✗ Small sample size	0.96	59.8
Analysis #2 (×8, ×209)	✗ Inconsistent acquisition ✓ Large sample size	0.65	1392.6
Analysis #3 (×8, ×209 → HACA3)	✓ Reduced inconsistency with harmonization ✓ Large sample size	0.95	61.3

- Even with guidelines, **consistency still matters**
  - Consistent acquisition: excellent ICC (0.96)
  - Inconsistent acquisition: poor ICC (dropped to 0.65)
- Solution: **Image harmonization** alleviates consistency issue
  - After harmonization: nearly identical ICC (0.95) as consistent acquisition
- Harmonization shows strong potential **clinical impact**
  - Improve patient tracking overtime
  - Improve multi-site trials

[1] Simpson et al. CTON 2021
[2] Dewey et al. CMSC 2022
[3] Zuo et al. CMIG 2023
[4] Huo et al. NeuroImage 2019

This work was supported in part by the Intramural Research Program of the National Institutes of Health, National Institute on Aging, in part by the TREAT-MS study funded by the Patient-Centered Outcomes Research Institute (PCORI) grant MS-1610-37115 (Co-PIs: Drs. S.D. Newsome and E.M. Mowry), in part by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-1746891, in part by the NIH grant (R01NS082347, PI: P. Calabresi), National Multiple Sclerosis Society grant (RG-1907-34570, PI: D. Pham), and the DOD/Congressionally Directed Medical Research Programs (CDMRP) grant (MS190131, PI: J. Prince).