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Age Differences in Functional Network Reconfiguration with Working Memory Training

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Introduction

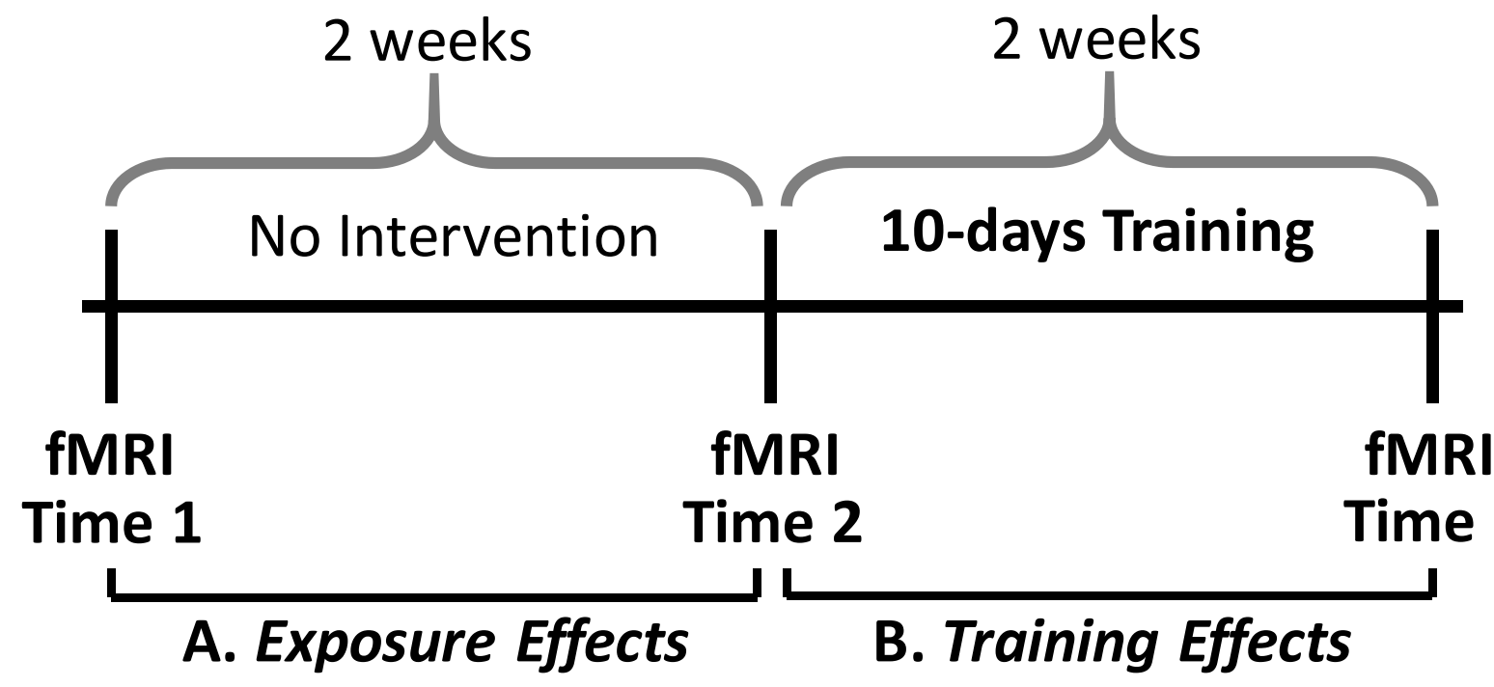
Demanding cognitive functions (e.g., working memory, WM), depend on the balance of neural network segregation and integration[1], which declines with age[2].

Cognitive training can improve performance and change brain activity even in older adults[3]. Less is known about training effects on functional connectivity.

Goal: To assess functional network reconfiguration in younger (YA) and older adults (OA) after 10 days of verbal WM training.

Methods

Study Design



2 weeks | 2 weeks

No Intervention | 10-days Training

fMRI Time 1 | fMRI Time 2 | fMRI Time 3

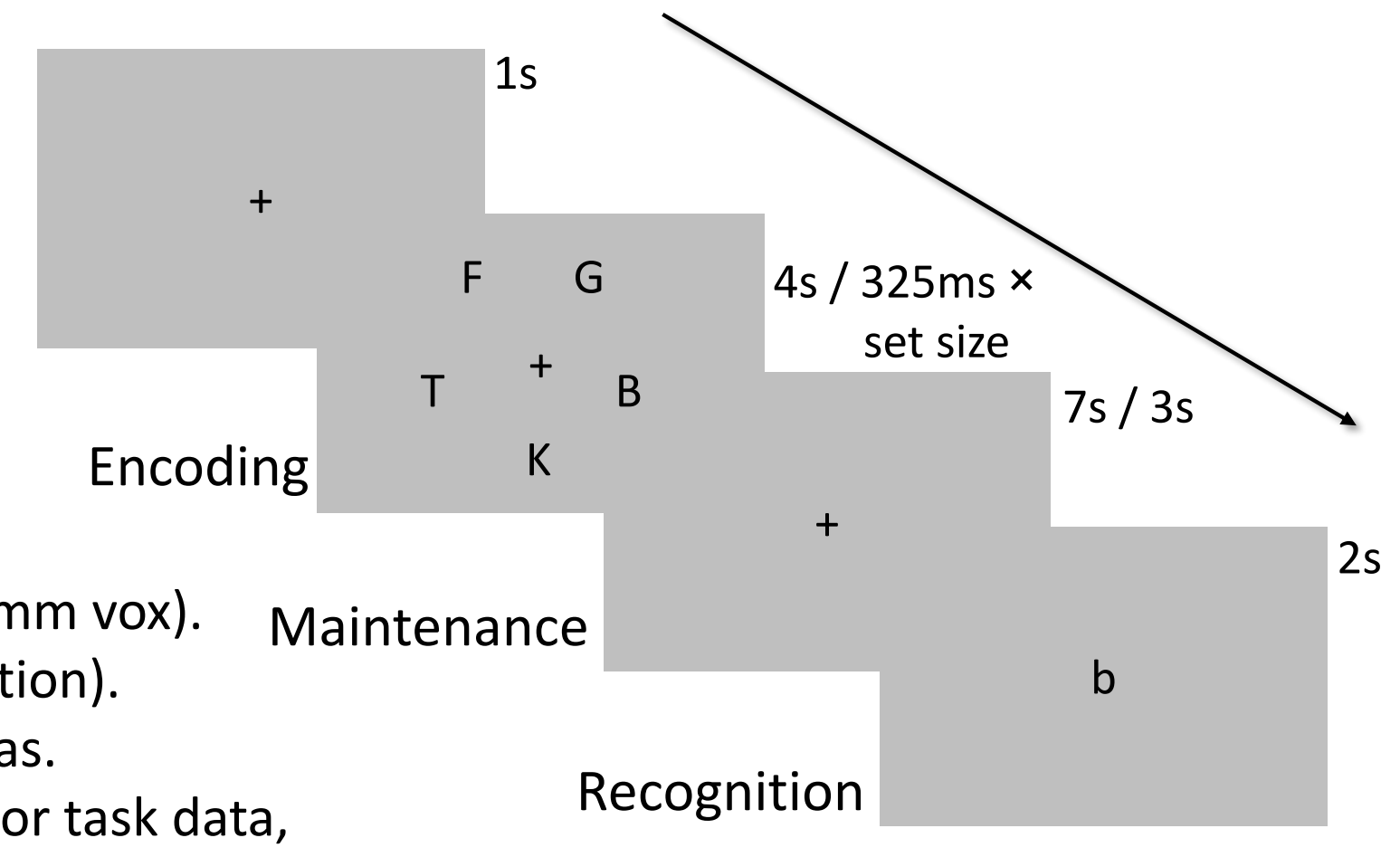
A. *Exposure Effects* | B. *Training Effects*

Demographics

	OA (N = 21)	YA (N = 21)
% Female	48	57
Age (S.D.)	67.81 (3.31)	21.33 (2.65)
Edu (S.D.)	17.05 (1.63)	14.81 (1.75)
MoCA (S.D.)	28.24 (1.61)	28.48 (1.50)

Note: 3 OA and 1 YA with incomplete data excluded from fMRI analyses.

fMRI *(Criterion)* Task / Adaptive Training Task



fMRI Task: Verbal WM (Sternberg) task with varying Load

- OA: Loads 1, 4-8; YA: Loads 1, 5-9; displayed in random order; 6 blocks of 24 trials

Training Task: Adaptive Verbal WM (Sternberg) Task

- Initial set size = 3 letters; sets increased if accuracy >86%, decreased if <72%
- 6 blocks of 14 trials/training session; duration ~20 min, consecutive weekdays

fMRI Acquisition & Analysis Whole-brain images (43 slices; TR=2s, TE=30ms, 3.4×3.4×3mm vox). Rest-state and task data preprocessed with SPM12 (slice-timing, realignment, normalization). Functional connectivity analysis performed with CONN, using the Power et al. (2011) atlas. Linear regression corrected for motion, outlier scans, and white matter and CSF signal. For task data, covariates accounted for encoding, probes, and incorrect trials; focus was on the maintenance interval. Residuals were band-pass filtered (.01- .15 Hz). Pearson correlations calculated between ROIs and z-transformed.

Behavioral Analysis: Within-subjects dissociation of *task-exposure* (Time1 vs. Time2) from *training* (Time2 vs. Time3) effects.

Graph-Theory Analysis performed with BCT. Matrices density-thresholded 10%-30%. Analyses performed at 3 levels:

(1) **Whole-brain.** *Modularity* assessed strength of network segregation. Calculated with Louvain algorithm (γ=1.3). Scores normalized by division to Maslov-Sneppen null. Consensus clustering used for representative partitions (τ=.4). Variation of information (VIn) quantified differences.

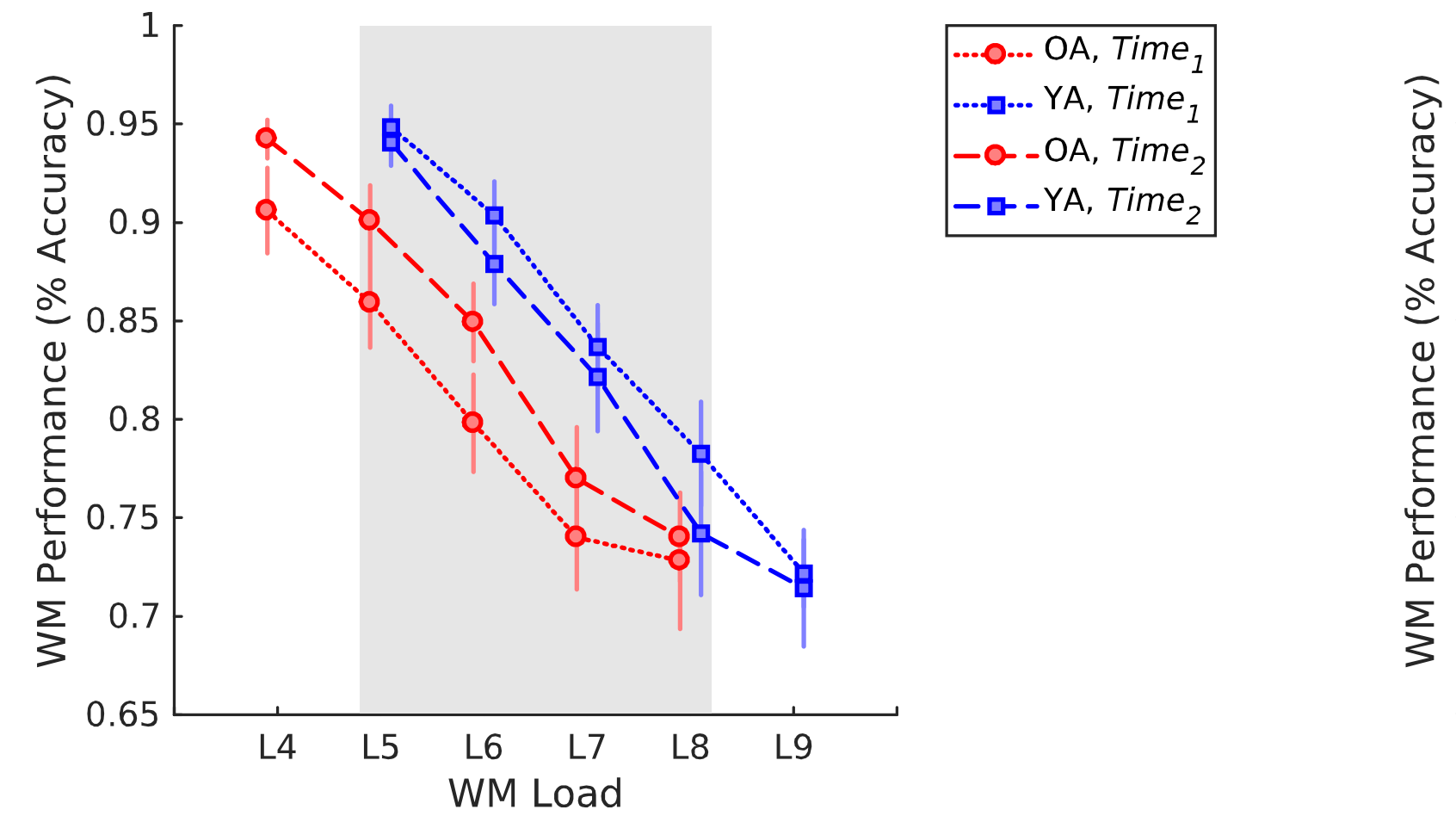
(2) **Individual networks**. Time1 node-module assignments used for pre- vs. post-training comparisons (Time2 vs. Time3). *Global efficiency* (E_{glob}; capacity for parallel information exchange) and *participation coefficient* (Partic; distribution of node's connections across modules) assessed within- and between-network communication, respectively.

(3) **Pairwise connectivity**. Differences due to training, load (highest vs. lowest), and their interaction assessed with Network Based Statistics (NBS).

Behavioral Results (fMRI task)

A. Exposure Effects (T1 vs. T2)

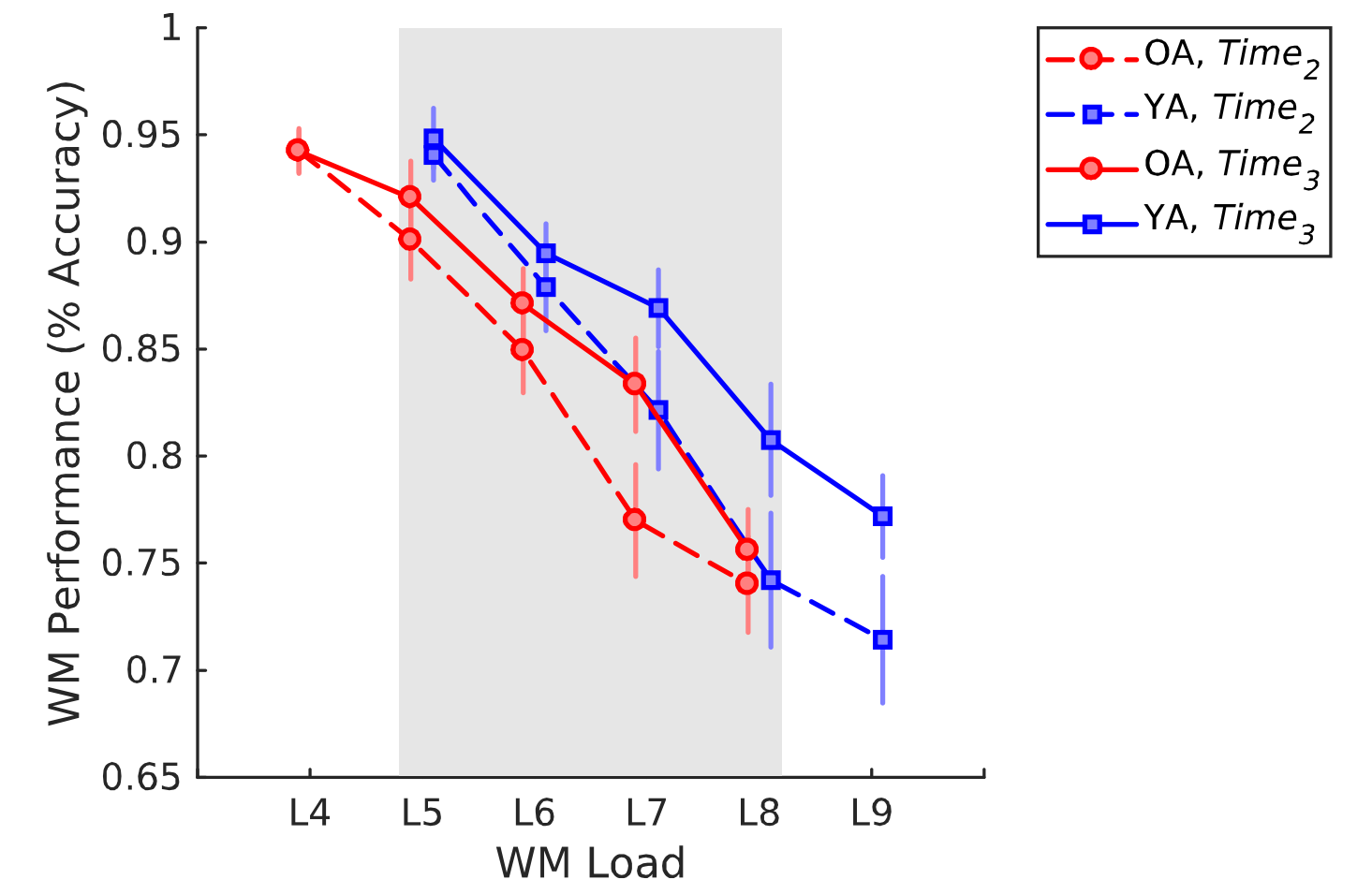
YA outperform OA; less so with task exposure



Time×Group: $F_{1,40}$=6.17, *p*=.017, η_p^2=.13.

B. Training Effects (T2 vs. T3)

Training improves performance for YA & OA



Time: $F_{1,40}$=13.04, *p*=.001, η_p^2=.25.

References

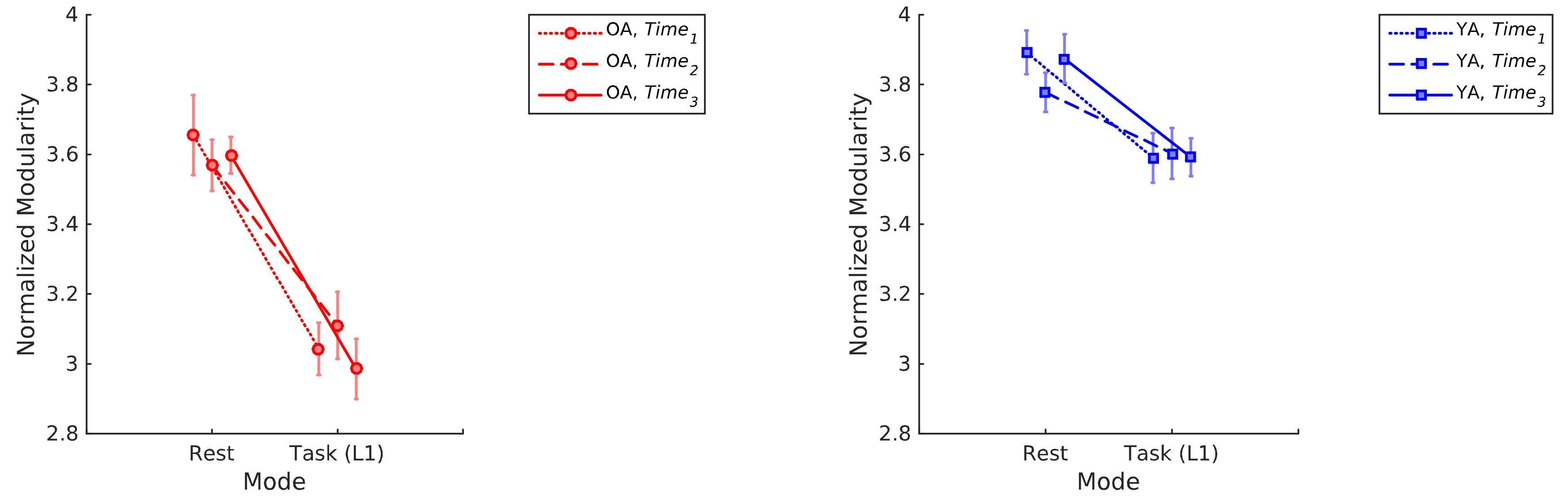
1. Dehaene et al. (1998). *PNAS*, 95(24), 14529-14534.
2. Damoiseaux (2017). *NeuroImage*, 46(4), 462-73.
3. Iordan et al. (*in press*). *NeuroImage,* [bioRxiv 869164].

Acknowledgements: NIA R21-AG-045460 to P.A.R.L.
M.B. is employed at the MIND Research Institute, whose interest is related to this work. S.M.J. has an indirect financial interest in the MIND Research Institute.

1. Whole-Brain Results

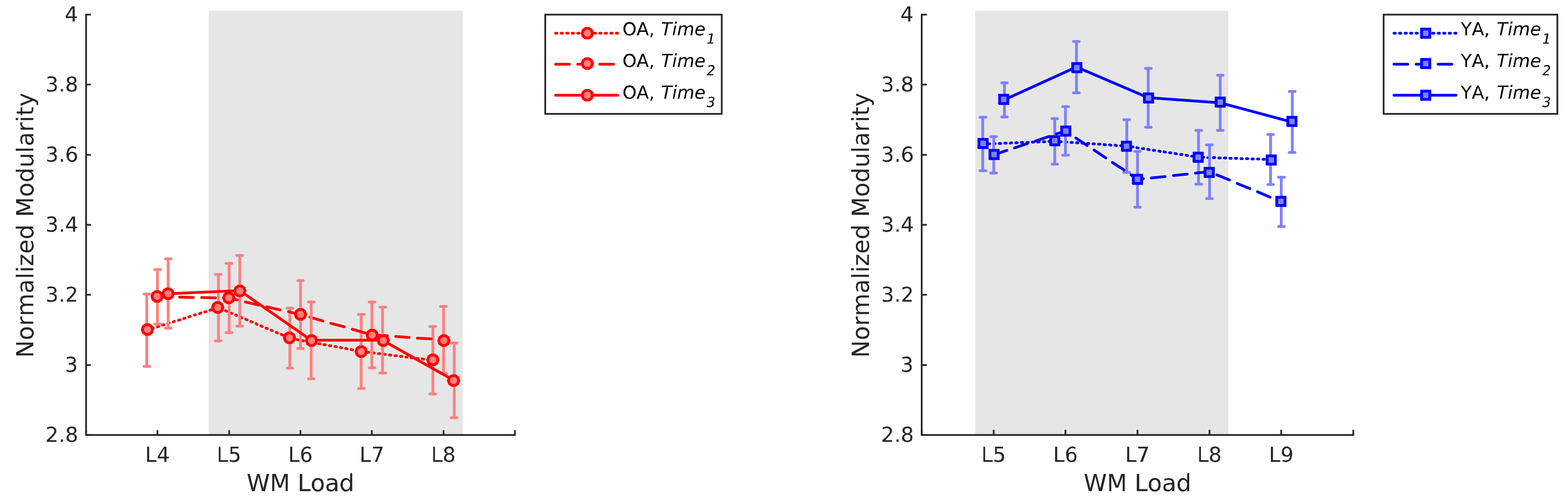
Modularity

Lower modularity and greater decrement with rest-to-task shift in OA



Group: $F_{1,36}$=32.37, *p*<.001, η_p^2=.47; **Mode**: $F_{1,36}$=141.94, *p*<.001, η_p^2=.8; **Group**×**Mode**: $F_{1,36}$=20.31, *p*<.001, η_p^2=.36.

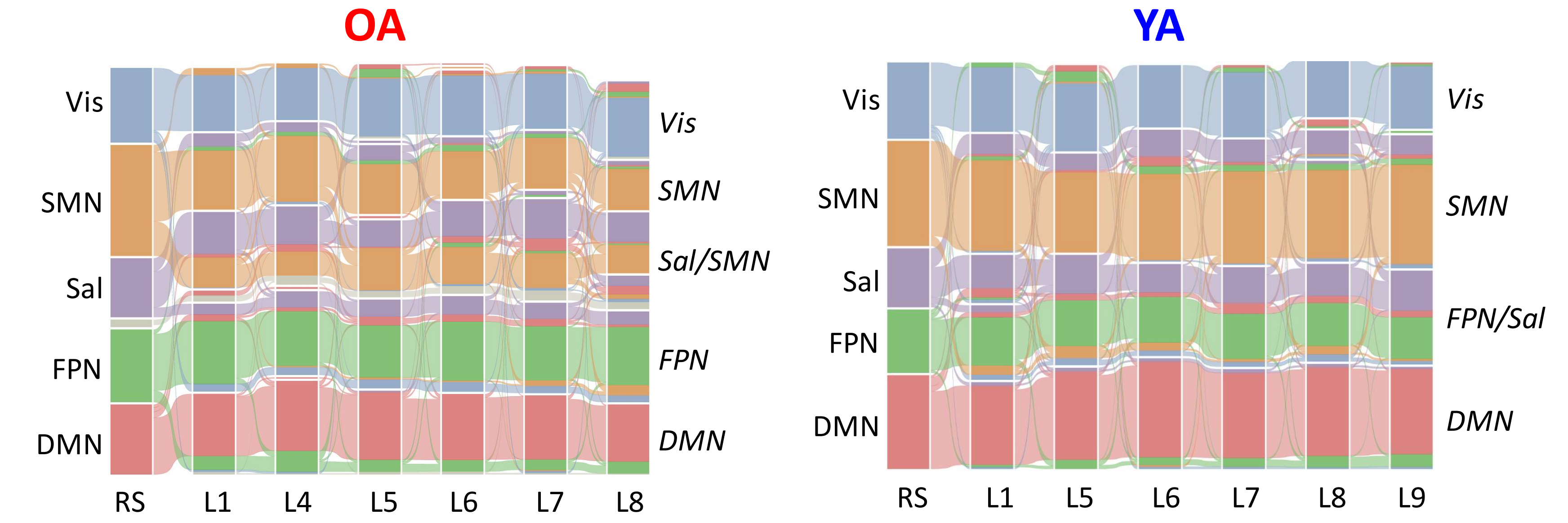
Increased task-related modularity with training in YA



Group: $F_{1,36}$=37.11, *p*<.001, η_p^2=.51; **Load**: $F_{3,108}$=6.01, *p*=.001, η_p^2=.14; **Group**×**Time**: $F_{2,72}$=4.66, p=.013, η_p^2=.12.
OA: No *task exposure* or *training* effects; **YA:** No *task exposure* but significant *training* effect, $F_{1,19}$=26.31, *p*<.001, η_p^2=.58.

Community Structure

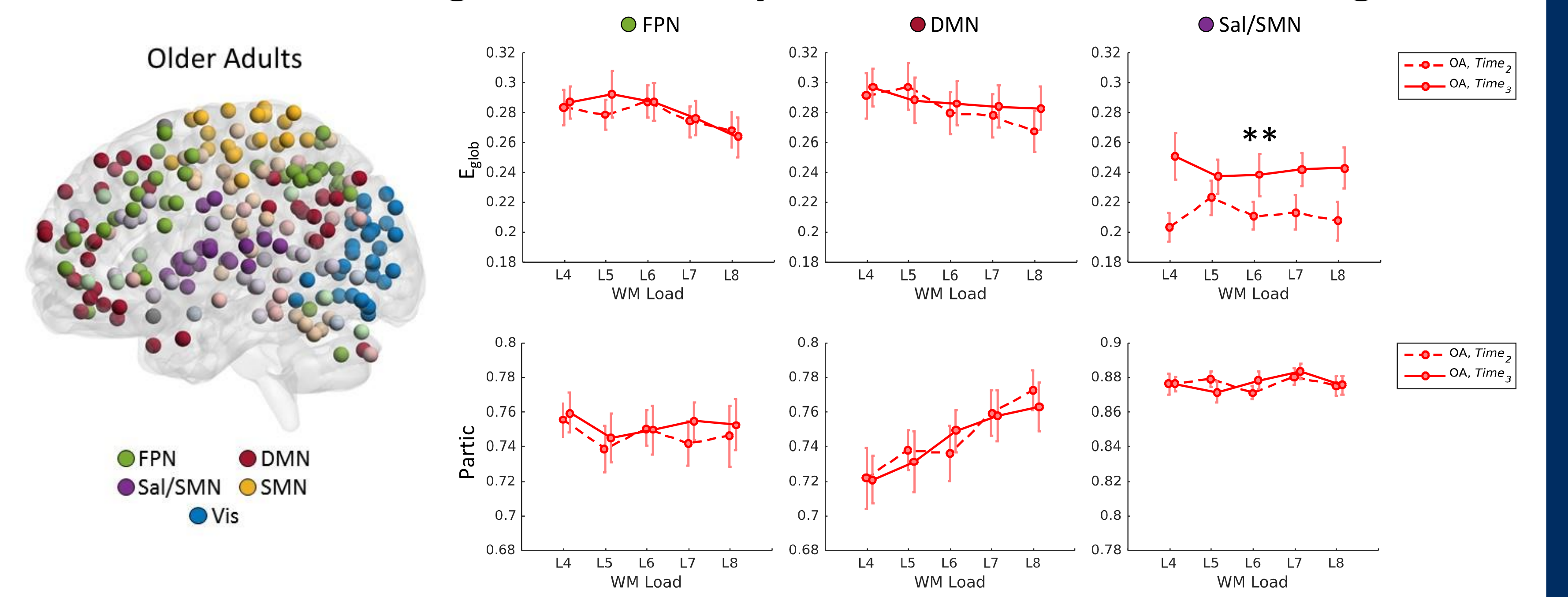
Node-module assignments across rest and task loads at T1



Greater reconfiguration (VIn) when switching from rest (RS) to task mode (L1) in OA than YA, $F_{1,36}$=67.35, *p*<.001, η_p^2=.65
Permutation tests across Load and Time: RS is different from all WM loads. No sig. differences between loads or across time.
Legend: DMN, default-mode; FPN, fronto-parietal; Sal, salience; SMN, sensorimotor; Vis, visual network.

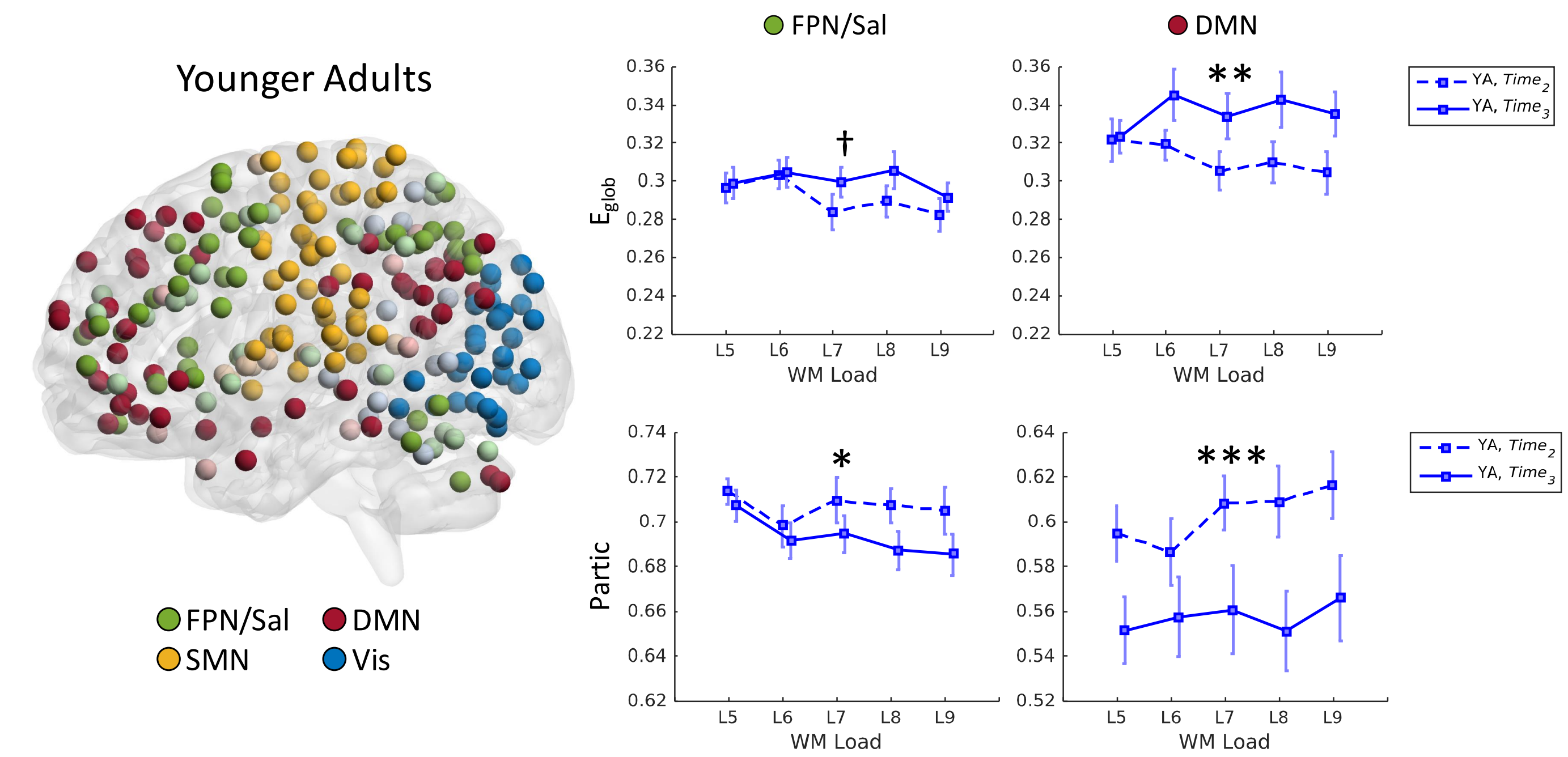
2. Individual Networks Results

OA: Increased global efficiency within Sal/SMN with training



Training effect on Sal/SMN E_{glob}, $F_{1,17}$=9.64, *p*=.006, η_p^2=.36; **Load effects** on FPN and DMN E_{glob}, and DMN participation.
Note: Statistics performed on nodes with stable module affiliation across all WM loads (i.e., bright color nodes).

YA: Increased global efficiency within and lower participation of FPN/Sal and DMN with training



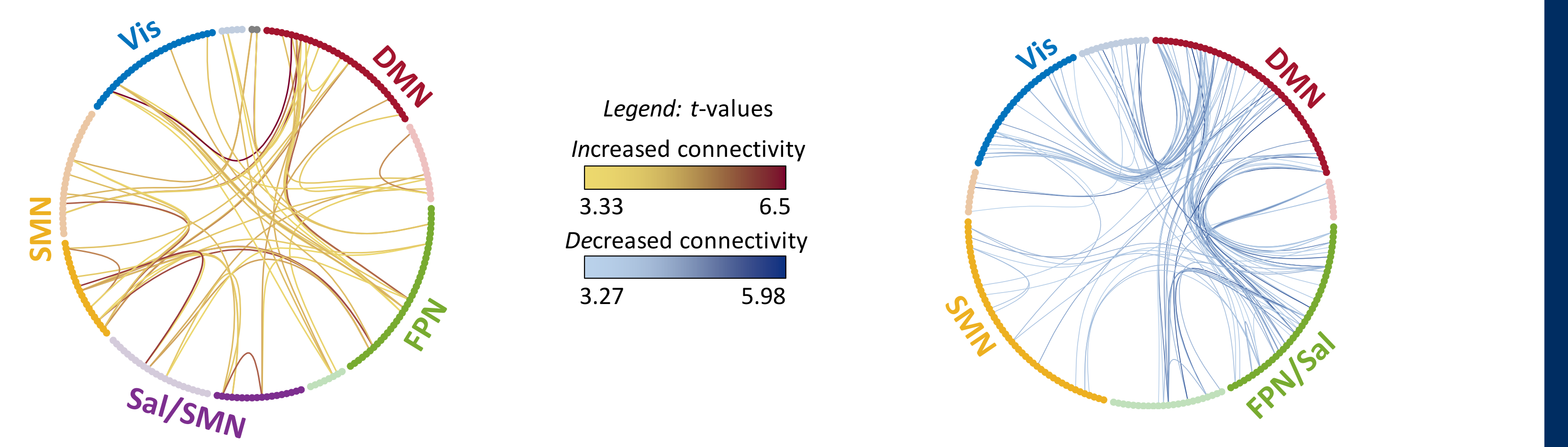
Legend:
†p=.078, *p<.05,
**p<.01, ***p<.001

Training effects on E_{glob} of FPN/Sal, $F_{1,19}$=3.47, *p*=.078, η_p^2=.16 and DMN. $F_{1,19}$=11.34, *p*=.003, η_p^2=.37, and on participation of FPN/Sal, $F_{1,19}$=7.99, *p*=.011, η_p^2=.3, and DMN, $F_{1,19}$=20.79, *p*<.001, η_p^2=.52.

3. Pairwise Connectivity Results

OA: Diffusely increased between-network connectivity with training

YA: Increased DMN segregation from FPN/Sal and Vis with training



Results displayed at *p*<.002 (p_{FWE}<.05). Bright/faded colors identify nodes with stable/variable module affiliation across WM loads.

Discussion

- Despite behavioral gains in both age groups, younger and older brains responded differently to WM training.
- Younger adults increase network segregation with training, suggesting more automated processing with enhanced expertise.
- Older adults maintain, and potentially amplify, a more integrated global workspace, which may enhance capacity for network engagement.
- In conclusion, WM training promotes different trajectories in functional network reconfiguration for younger and older adults.