Functional alignment with anatomical networks is associated with cognitive flexibility

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Medaglia J D, et al. Functional alignment with anatomical networks is associated with cognitive flexibility. Nature human behaviour, 2018.

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What is Cognitive flexibility?

◆Cognitive flexibility describes the human ability to switch between modes of mental function to achieve goals. Mental switching is accompanied by transient changes in brain activity, **which must occur atop an anatomical architecture** that bridges disparate cortical and subcortical regions via **underlying white matter tracts.**

◆The **physiological origins of cognitive flexibility** are thought to lie in **corticobasal ganglia–thalamocortical loops**: **regions of the fronto-parietal and cingulo-opercular systems** are activated by cognitive switching tasks.

◆All of these regions anatomically connect to **subcortical regions**, which are postulated to mediate processes that both suppress prepotent motor responses and transition between behavioural outputs to meet task goals. Interactions between cortical systems and motor outputs are thought to be anatomically mediated by subcortical circuits.

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Question

- However, understanding exactly **how this circuit supports task switching has remained challenging**, particularly because it requires **the integration of regional activity, inter-regional anatomical connectivity and observable measures of behaviour.**
- Whereas regional activity and behavioural markers of cognitive flexibility are relatively straightforward to estimate, it is less straightforward to integrate these features with the white matter structure that guides the propagation of functional signals.
- Conceptually, underlying white matter network organization in the brain physically mediates communication among brain regions. However, **analytic frameworks that explicitly use white matter structure to constrain cognitively relevant functional signals are lacking.**

Methods

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- **Subject: 28 individuals** (mean age = 25.6, s.d. = 3.5, 13 females).
- **Behavioural task:** All participants completed a local–global perception task based on **classical Navon figures**. Local–global stimuli consisted of four shapes—a circle, X, triangle or square—that were used to build the global and local aspects of the stimuli.
- **Diffusion spectrum imaging acquisition and processing**: Diffusion spectrum images were acquired on a Siemens 3.0T Tim Trio for all subjects along with a T1-weighted anatomical scan at each scanning session. DSI data were reconstructed in DSI Studio to **construct an anatomical connectivity matrix A**.
- **Functional imaging acquisition and processing**: fMRI images were acquired during the same scanning session as the DSI data on a 3.0T Siemens Tim Trio whole-body scanner with a whole-head elliptical coil by means of a single-shot gradient-echo T2*.

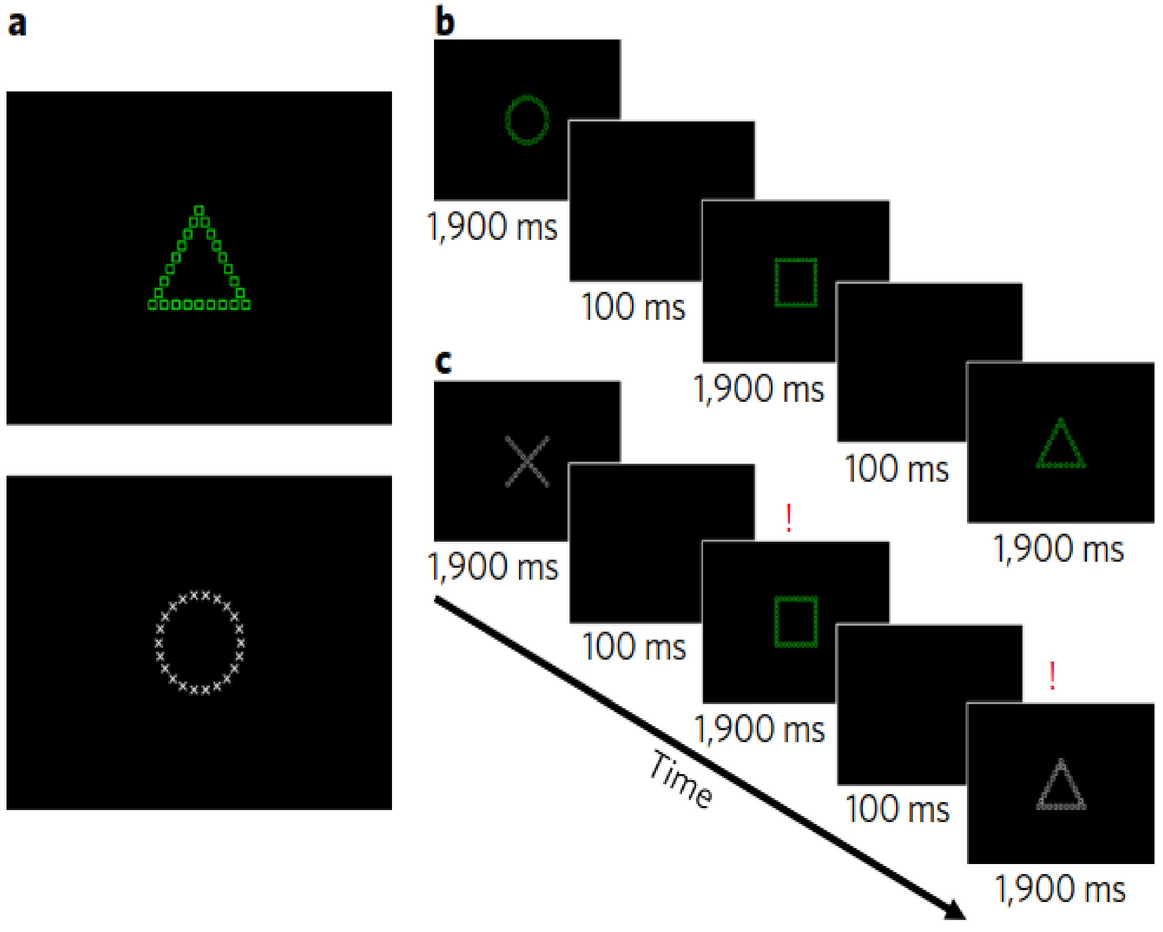

Fig. 1 Cognitive task requiring perceptual switching.

Methods

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◆ Functional decomposition into anatomical networks

- We used **graph Fourier transform(GFT) to represent the BOLD signals in the graph domain.**
- This allowed us to take observed BOLD time series and **examine the extent to which they were aligned to or liberal from the underlying graph representing the white matter connections between regions**.
- GFT could be used to study **how the topology of an individual's anatomical network informed the expected structure of the BOLD signal.**

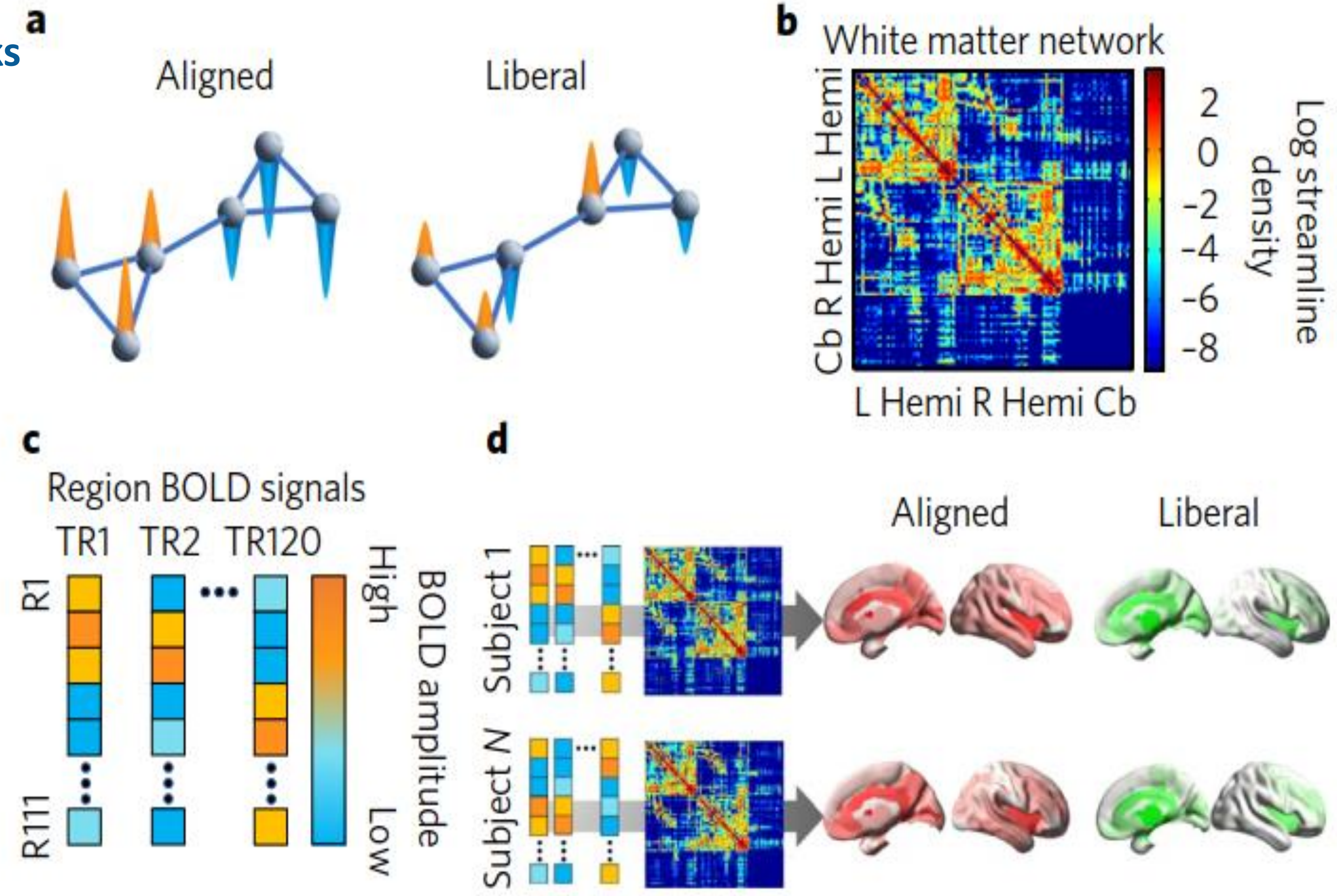

Fig. 2 Multimodal approach to the study of cognitive switching using emerging graph signal processing tools.

Methods

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GFT of the graph signal: $\tilde{\mathbf{x}} = \mathbf{v}^T \mathbf{x}$ Where, $A = V \Lambda V^T$

IGFT of the graph signal: $\mathbf{x} = \mathbf{V} \widetilde{x}$

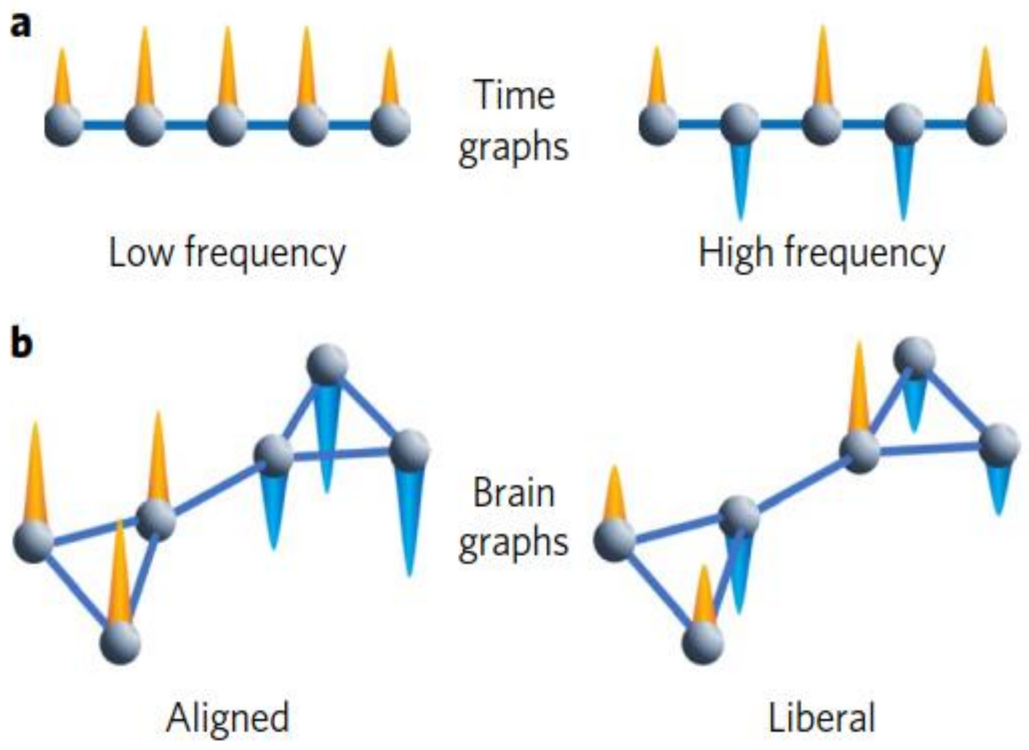

Fig.4 Signal frequency in the time domain versus alignment in the graph domain

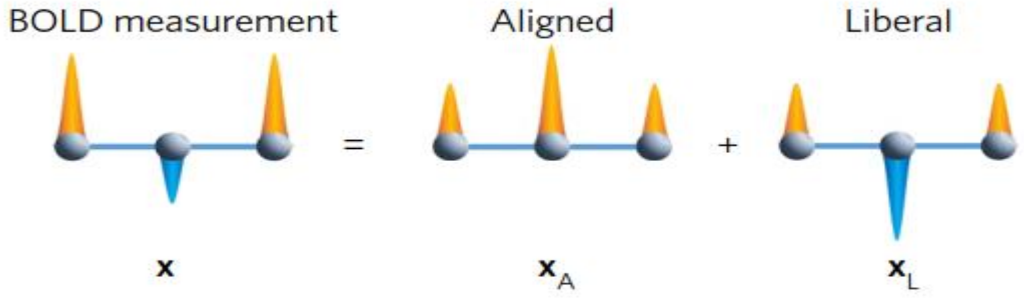

Fig. 3 Signal decomposition into anatomy.

◆ Relating signals to behaviour

We computed a **partial Pearson's correlation** between the mean **aligned and liberal signal value for each subject and their median switch cost** (median response time during switching trials versus no-switching trials) .

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Results

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◆ BOLD signal alignment concentrations across the brain

- Aligned signals were concentrated within **default mode, fronto-parietal, cingulo-opercular** and **subcortical systems.**
- The liberal signals were concentrated largely in the **subcortical system**.
- **The insula, anterior cingulate and subcortical systems shared both aligned and liberal signals**, indicating that the content of BOLD signals in these areas are complex with respect to underlying anatomy

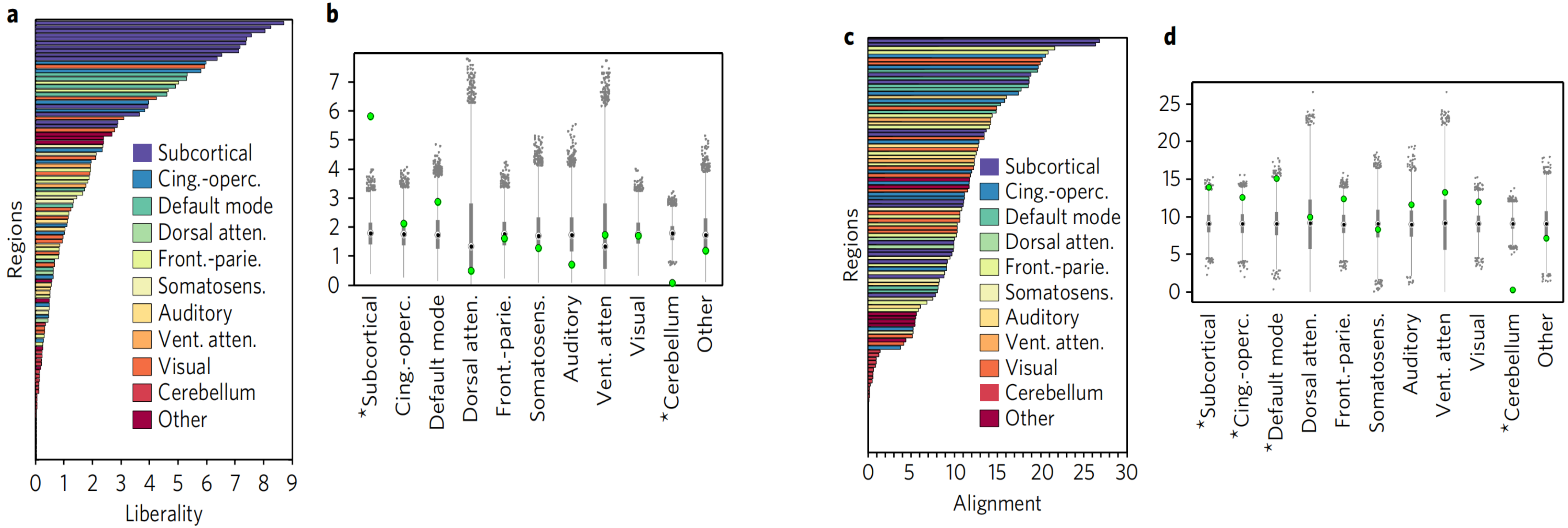

Fig.5 Non-parametric permutation test for signal concentration within cognitive systems

Results

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◆ Associations between BOLD signal alignment and cognitive switch costs

- **We observed that variability in aligned signals was not associated with switch costs (R = 0.15, P = 0.43, accounting for 2% of the variance), whereas variability in liberal signals accounted for 32% of the variance (R = 0.57, P = 0.002).**

- Using **aligned signals as covariates in a partial correlation analysis between liberality and switch costs revealed that the correlation remained significant** (R = 0.55, P = 0.002).

- Among the liberal signals, lower values of liberality (that is, relative alignment) were also associated with lower switch costs during both fixation (R = 0.62, P = 0.0006) and non-switching (R = 0.71, P = 0.0001) perceptual blocks.

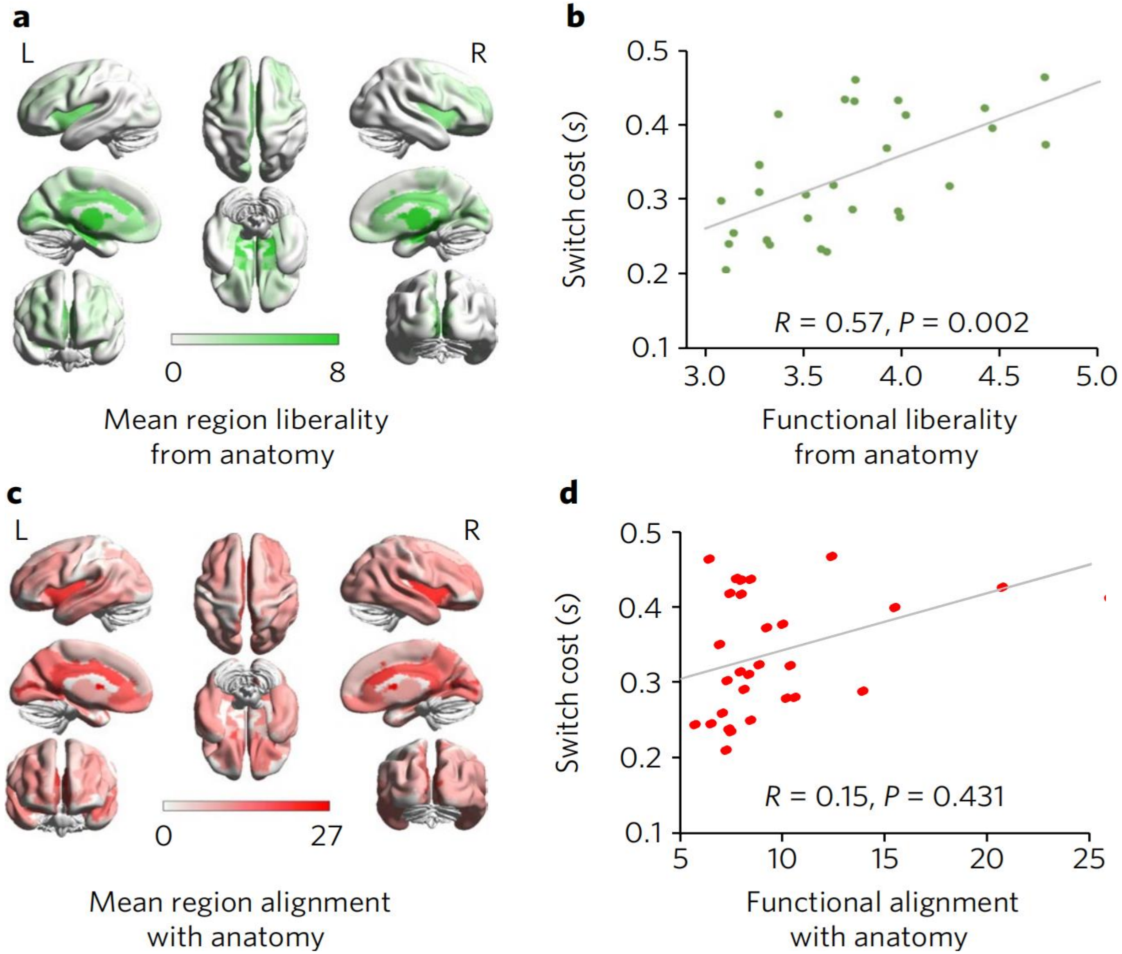

Fig. 6 Lower independence is associated with lower switch costs.

Conclusion

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- By using emerging tools from **graph signal pocessing**,we found that the **alignment between functional signals and the architecture of the underlying white matter network was associated with greater cognitive flexibility across subjects.** By computing a concise measure using multi-modal neuroimaging data, we uncovered an **integrated structure–function relation of human behaviour**.
- **By examining functional signal alignment within underlying white matter networks, we identify an important definition of dynamic contributions to cognitive switching that discriminates between the contributions of subcortical and other systems.**
- Similar applications to other large multimodal neuroimaging datasets could contribute to biomarker analyses in psychiatric disease and neurological disorders, many of which are associated with deficits in executive function.

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THANK YOU！