Functional connectivity patterns of optic flow-sensitive regions during visual path integration are associated with self-reported spatial navigation ability

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Main Questions

(1) Are task-related functional connectivity (FC) patterns of optic flow-sensitive (OF-sensitive) cortical regions related to self-reported spatial navigation ability?
(2) Do task-related FC patterns of OF-sensitive cortical regions differ according to navigational task demands?

Introduction

- Spatial navigation ability significantly varies between individuals, and the mechanisms underlying this variability are not clear (Wolbers & Hegarty, 2010).
- Because spatial navigation is a complex, multisensory skill, it is helpful to break it down into simple and relevant sub-components in order to study it.
- Path integration is a simple and relevant sub-component of spatial navigation that can aid in the study of variation in navigation ability between individuals.
- Optic flow (OF) provides a source of self-motion information while moving through the environment and is sufficient for humans to path integrate. OF-sensitive cortical regions have also been defined.
- Recently, a functional link was reported between OF-sensitive regions and navigationally-responsive brain regions (i.e. hippocampus, retrosplenial cortex (RSC)) in humans while they performed a goal-directed navigation task (Sherrill et al., 2015).
- In this study, we set out to determine whether:
  (1) Variability in the FC patterns of OF-sensitive regions during 2 tasks involving navigationally-related stimuli is associated with variability in self-reported spatial navigation ability
  (2) The FC patterns of OF-sensitive regions differed according to navigational task demands

Methods

- Participants viewed 4 runs of a visual path integration (VPI) task, followed by 4 runs of a turn counting (TC) task, followed by 4 runs of an optic flow (OF) localizer task in the MRI scanner. After scanning, participants completed the Santa Barbara Sense of Direction (SBSoD) scale (Hegarty et al., 2002).
- Functional images with blood oxygenation level dependent (BOLD) contrast were acquired using T2*-weighted EPI sequences (TR/TE = 2000/28 ms, voxel size = 3 x 3 x 3 mm). Structural T1-weighted images were acquired on all participants (TR/TE = 6.7/3.1 ms, voxel size = 1.1 x 1.1 x 1.2 mm).
- All image processing performed in FSL v5.08 using FEAT v6.00.
- OF-sensitive regions were defined based on where brain activity was significantly greater during coherent dot motion compared to scrambled dot motion during the OF localizer task at the group level.
- Functional connectivity (FC) analyses between OF-sensitive regions and the rest of the brain were carried out using psychophysiological interactions (PPI) analyses.
- Cluster thresholding was used with a Z threshold of 2.3 and a cluster p threshold of 0.05 in all analyses. For higher-level analyses, FLAME 1+2 was used with the same parameters.
- "Summary maps" of FC analyses were created by thresholding significant FC maps and summing. Summary maps were overlaid on 7 brain networks (Yeo et al., 2011) to contextualize results.

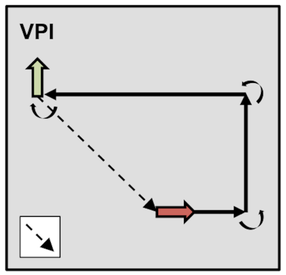
Participant Information

- 15 young healthy participants (8 male, 7 female)
- Mean age: 27.1 (± 2.66, s.d.) years, range = 24-34 years
- 14 right handed
- Mean SBSOD score: 4.71 (± 1.17, s.d., range = 2.33-6.33)
- Mean VPI task performance: 95.4% (± 8.59%, s.d.)
- Mean TC task performance: 91.3% (± 16.3%, s.d.)
- No significant effect of sex on SBSoD score or task performance

Tasks

Visual Path Integration (VPI)

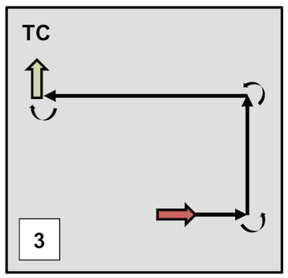
Goal: Keep track of one's starting location over the course of a short path (Navigational Demands)



- 32 trials
- Paths had 0, 1, 2, or 3 turns
- Paths were approximately 30 seconds in duration
- (above left) Response screen, VPI trial
- (above right) Birds-eye view of a 3-turn path and the correct response

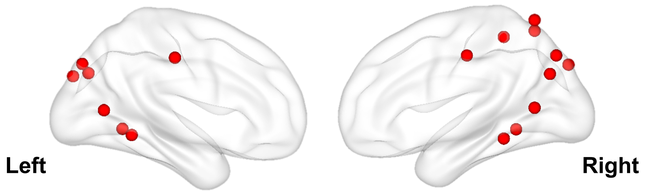
Turn Counting (TC)

Goal: Count the number of turns taken over the course of a short path (No Navigational Demands)

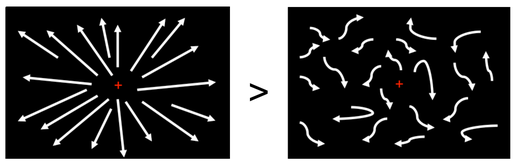


- 32 trials, same types of paths as VPI
- (above left) Response screen, TC trial
- (above right) Birds-eye view of a 3-turn path and the correct response

OF Localizer & OF-Sensitive Regions



- OF-sensitive regions (above, red) were those that showed greater brain activity during coherent (bottom left) versus scrambled (bottom right) dot motion at the group level
- 17 OF-sensitive regions (above, shown in red) were defined
- FC patterns of each OF-sensitive region were mapped during VPI and TC

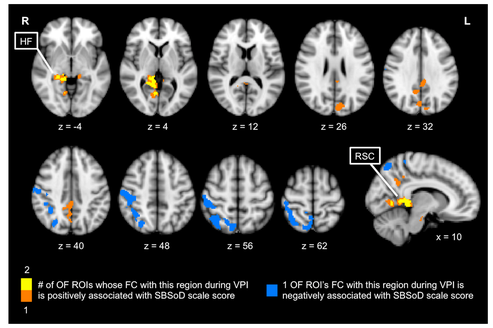


coherent scrambled

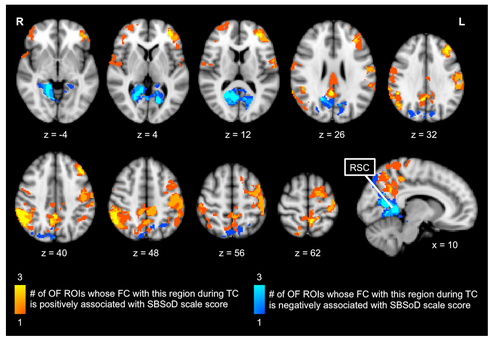
Results

FC Patterns of OF-Sensitive Regions Are Related to Self-Reported Navigation Ability

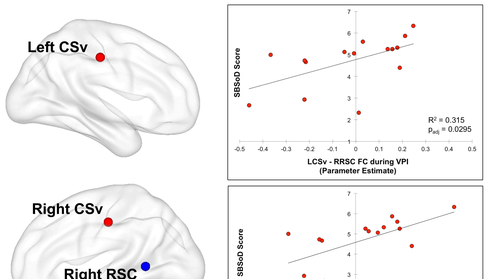
VPI



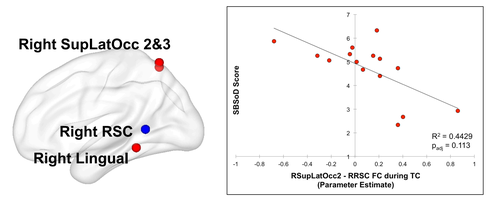
TC



Better Navigators: stronger FC between right RSC and OF-sensitive regions (L/R cingulate sulcus visual area (CSv)) during VPI

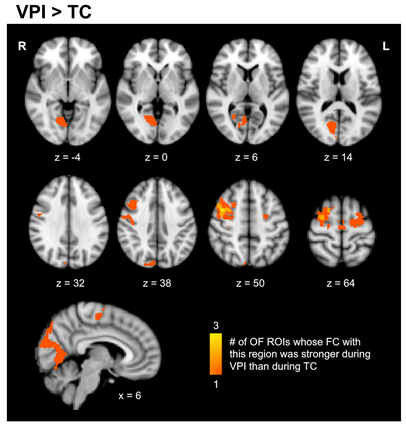


Better Navigators: weaker FC between right RSC and OF-sensitive regions in right superior lateral occipital cortex and lingual gyrus during TC

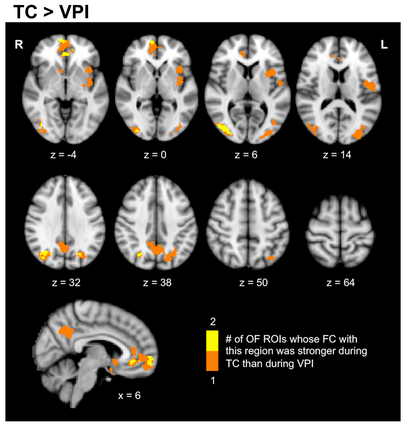


FC Patterns of OF-Sensitive Regions Differ According to Navigational Demands

VPI > TC



TC > VPI



- Stronger FC between OF-sensitive regions and Dorsal Attention Network (DAN) and Frontoparietal Network (FPN) regions during VPI vs. TC.
- Stronger FC between OF-sensitive regions and Default Mode Network (DMN) and Visual Network (VIS) regions during TC vs. VPI.

Summary

- Functional connectivity patterns between OF-sensitive regions and right retrosplenial cortex during visual path integration and turn counting were significantly associated with self-reported spatial navigation ability.
- OF-sensitive regions showed stronger functional connectivity with regions in the DAN and FPN during visual path integration and stronger functional connectivity with regions in the DMN and VIS during turn counting.