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Reorganization of Resting-State Functional Connectivity with a Feature-Representation Region after Visual Perceptual Training

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論 文 内 容 の 要 旨

Repeated exposure to a specific visual feature improves perceptual sensitivity and behavioural accuracy to the trained feature. This process is known as visual perceptual learning (VPL), and is considered an effective tool for exploring experience-dependent plasticity in the brain. Previous studies using functional magnetic resonance imaging (fMRI) in humans have revealed that different brain regions contribute to VPL in distinct ways, depending on their specialized roles. These studies have typically examined how brain activation to specific visual stimuli changes over the course of perceptual training. For instance, several studies have shown that stimulus-induced activation in brain regions representing specific visual features (e.g., the early visual cortex) tends to increase after intensive perceptual training, whereas activation in regions related to higher-order cognitive processes tends to decrease after training. Other studies have reported refinements in neural representations of trained visual features after VPL, indicating training-induced plasticity in feature-representation regions. While these findings have provided useful insights into the "online" processes supporting VPL, it is also known that "offline" processes after task completion (e.g., consolidation during sleep) play critical roles. However, because the majority of existing fMRI studies have exclusively investigated brain activation during task periods, the contribution of offline mechanisms to VPL remains to be unraveled. The importance of post-task offline processes in VPL has typically been studied by focusing on sleep-related consolidation processes. However, recent studies have also highlighted the importance of wakeful resting periods immediately after training. Neuroimaging studies utilizing resting-state functional connectivity (rs-FC) are particularly useful for investigating experience-dependent reorganization in the brain after performing cognitive tasks. Evidence from diverse domains of cognitive neuroscience research has suggested that post-task rs-FC changes reflect recent visual/cognitive experiences and further predict subsequent performance of memory and learning. Studies of episodic memory are notable examples, showing that rs-FC between category-selective regions (e.g., the fusiform face area) and memory-related regions (e.g., the hippocampus) during wakeful rest immediately after performing encoding tasks is predictive of subsequent memory performance. Although VPL and episodic memory formation are supported by different neural substrates, both involve experience-induced plasticity as underlying mechanisms. This raises the possibility that rs-FC during wakeful rest immediately after training may also play a key role in VPL. Only a few studies have investigated training-induced rs-FC changes after VPL, and the results have been mixed. One study examined rs-FC before and after intensive training on a visual shape discrimination task, finding that rs-FC between the visual feature representation region (i.e., V3) and the dorsal attention system (e.g., the frontal eye field and superior parietal lobule) decreased after training. However, this study investigated the effects of intensive training over several days (2–9 days), and did not examine rs-FC changes in the early learning phase. In contrast, another fMRI study used visual motion discrimination training with a much shorter timescale (~90 min), finding that rs-FC between the hippocampus and striatum increased during a wakeful rest period immediately after training. While this study revealed rapid reorganisation of rs-FC after a brief period of perceptual training, no rs-FC changes were detected in the visual feature representation region, unlike the earlier study. Thus, it remains unclear whether visual feature representation regions show training-induced rs-FC changes immediately after training. In the current fMRI study, we examined whether a brief period of visual perceptual training induced rapid reorganisation of rs-FC changes immediately after training in the visual feature representation regions. Twenty one participants were trained on a visual motion discrimination task for a short period (~30 min), in which they judged the direction of coherently moving dots randomly chosen from three coherence levels (20, 40 and 80%). We localized the MT+, a brain region representing visual motion, by analysing the

parametric effects of motion coherence on stimulus-induced activation during the task fMRI (t-fMRI) session. Importantly, we obtained resting-state fMRI (rs-fMRI) scans before and immediately after the task to examine whether short-term visual motion discrimination training induces rs-FC changes with the MT+. Furthermore, we examined whether training-induced rs-FC changes immediately after training were associated with subsequent performance improvement. To examine this issue, we invited the same participants back on the second day of the experiment to perform the motion discrimination task in the scanner.We found that stimulus-induced activation increased with motion coherence in the middle temporal cortex (MT+), a feature-specific region representing visual motion. On the other hand, stimulus-induced activation decreased with motion coherence in the dorsal anterior cingulate cortex (dACC) and bilateral insula, regions involved in decision making under perceptual ambiguity. Moreover, by comparing pre-task and post-task rest periods, we revealed that resting-state functional connectivity (rs-FC) with the MT+ was significantly increased after training in widespread cortical regions including the bilateral sensorimotor and temporal cortices. In contrast, rs-FC with the MT+ was significantly decreased in subcortical regions including the thalamus and putamen. Importantly, the training-induced change in rs-FC was observed only with the MT+, but not with the dACC or insula. Thus, our findings suggest that perceptual training induces plastic changes in offline functional connectivity specifically in brain regions representing the trained visual feature, emphasising the distinct roles of feature-representation regions and decision-related regions in VPL.