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RESEARCH****Research Report****Neural substrates for visual pattern recognition learning in Igo****Kosuke Itoh^{a,*}, Hideaki Kitamura^{a,b}, Yukihiro Fujii^{a,c}, Tsutomu Nakada^{a,d}**^aCenter for Integrated Human Brain Science, Brain Research Institute, University of Niigata, 1-757 Asahimachi-Dori, Niigata, 951-8585, Japan^bDepartment of Psychiatry, Graduate School of Medical and Dental Sciences, University of Niigata, Japan^cDepartment of Neurosurgery, Brain Research Institute, University of Niigata, Japan.^dDepartment of Neurology, University of California, Davis, USA

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ABSTRACT

Different contexts require different visual pattern recognitions even for identical retinal inputs, and acquiring expertise in various visual-cognitive skills requires long-term training to become capable of recognizing relevant visual patterns in otherwise ambiguous stimuli. This 3-Tesla fMRI experiment exploited *shikatsu-mondai* (life-or-death problems) in the Oriental board game of Igo (Go) to identify the neural substrates supporting this gradual and adaptive learning. In *shikatsu-mondai*, the player adds stones to the board with the objective of making, or preventing the opponent from making *nigan* (two eyes), or the topology of figure of eight, with these stones. Without learning the game, passive viewing of *shikatsu-mondai* activated the occipito-temporal cortices, reflecting visual processing without the recognition of *nigan*. Several days after two-hour training, passive viewing of the same stimuli additionally activated the premotor area, intraparietal sulcus, and a visual area near the junction of the (left) intraparietal and transverse occipital sulci, demonstrating plastic changes in neuronal responsivity to the stimuli that contained indications of *nigan*. Behavioral tests confirmed that the participants had successfully learned to recognize *nigan* and solve the problems. In the newly activated regions, the level of neural activity while viewing the problems correlated positively with the level of achievement in learning. These results conformed to the hypothesis that recognition of a newly learned visual pattern is supported by the activities of fronto-parietal and visual cortical neurons that interact via newly formed functional connections among these regions. These connections would provide the medium by which the fronto-parietal system modulates visual cortical activity to attain behaviorally relevant perceptions.

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1. Introduction

Neural recognition of previously experienced visual patterns facilitates the cortical analysis of complex visual input, leading to efficient behavior (Palmeri et al., 2004). However, what constitutes a recognized visual pattern depends upon behavioral context, and top-down attentional processes need

to shape perception to accommodate task demands. Consequently, *visual pattern recognition learning*, i.e., the process of becoming able to recognize previously unfamiliar visual patterns through experience, is an essential component to learning many types of visual-cognitive tasks. This is evident when an individual acquires the visual recognition skills to become a radiologist, art connoisseur, or commodity chart

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analyst, for example. Given exactly the same stimulus, experts readily recognize or “see” task-relevant visual patterns that untrained individuals do not. Considering that it may take years of extensive training to acquire expertise in such skills, visual pattern recognition learning is likely underpinned by gradual and plastic changes in neural activity and connectivity. However, the neural substrates for this learning process remain obscure, despite growing knowledge of the visual pattern recognition process *per se* (e.g., Kanwisher et al., 1997; Riesenhuber and Poggio, 2002; Grill-Spector and Malach, 2004). This functional magnetic resonance imaging (fMRI) study investigated this issue.

We were specifically interested in the role of the fronto-parietal cortical network in long-term visual pattern recognition learning. Consolidated memory for learned visual patterns may eventually reside within the occipito-temporal visual cortices (Sergent et al., 1992; Allison et al., 1994; Malach et al., 1995), but during the learning phase, visual cortical activity/connectivity needs to be plastically modulated by an external “critic” that sends feedback to these areas to reflect the successfulness of their processing with regard to the task. Although the specific neural substrate mediating this function in visual pattern recognition learning has not been identified, the fronto-parietal network represents a well-qualified candidate. The frontal and parietal association cortices function collectively as a top-down attentional system to modulate visual cortical activity during perception in a context-dependent manner (Kastner and Ungerleider, 2000; Kanwisher and Wojciulik, 2001; Yantis and Serences, 2003). If repeatedly exerted, such attentional control may contribute to reorganize visual cortical circuitry to implement long-term learning (Law et al., 2005; Sigman et al., 2005). Once learned, retrieval of visual stimulus representations from stored memory may be mediated by the fronto-parietal top-down attentional mechanisms, as has been demonstrated with mental imagery (Ishai et al., 2000; Mechelli et al., 2004) and recognition tasks (Kahn et al., 2004; Wagner et al., 2005).

Thus, during the period of visual pattern recognition learning, substantial interactions are expected to take place among the activities of fronto-parietal and visual cortical neurons to support visual processing of the task-relevant stimuli. Moreover, because later stages of learning must build on what has been learned previously, the strength and nature of the neural interactions should change plastically over time, starting from the pre-training state in which there are no such interactions (for those specific stimuli). Therefore, our prediction in this experiment was that, as an effect of being trained on a visual-cognitive task, fronto-parietal activation and concomitant changes in visual cortical activity would accompany perception of the task-relevant stimuli to reflect the formation of stimulus-specific, functional connections among these regions. These connections would provide the medium by which the fronto-parietal system exerts top-down attentional control on visual cortical activity to attain relevant perceptions when viewing task-related stimuli, in a manner that is adaptable to different stages of learning.

We exploited the Oriental board game of Igo (Go) to study visual pattern recognition learning in the context of learning an ecologically valid cognitive task. In the game, two players take turns to place black or white round stones on a 19-by-19

grid, with the objective to control a larger part of the board than the opponent. A new stone can be placed on any one of the vacant intersections of the grid, as long as it secures its own *liberty* (*kokyu-ten* or breathing space in Japanese), defined as a vacant intersection immediately adjacent to the stone or to the group of connected stones (Fig. 1A). Stones are captured by the opponent and are removed from the board when all of their *liberties* are lost and become “dead” (Fig. 1B); otherwise the stones stay in their position unlike in chess. As the game proceeds, highly complex black-and-white territorial patterns emerge on the board, some examples of which can be found at http://en.wikipedia.org/wiki/List_of_famous_go_games. Further information about Igo can be obtained at, for example, <http://www.usgo.org/> and [http://en.wikipedia.org/wiki/Go_\(board_game\)](http://en.wikipedia.org/wiki/Go_(board_game)).

Igo provides a suitable paradigm for studying visual pattern recognition learning for several reasons. It is a complex task requiring years of training to reach a professional level, and advanced players have specialized pattern recognition skills for the game patterns (Reitman, 1976) as in chess (de Groot, 1978; Chase and Simon, 1973). The importance of human pattern recognition skill in playing Igo has become widely acknowledged (Johnson, 1997), due to the fact that today’s fastest computers cannot compete even at the entrance professional level (Bouzy and Cazenave, 2001), although IBM’s Deep Blue defeated the reigning world champion Kasparov in a chess match a decade ago. Igo is very popular (much more popular than chess) in Japan where the study was conducted, and there are many published practice problems that are systematically organized by the level of difficulty, providing researchers with useful sources of externally validated stimuli. Evidently, many of the factors that make chess a useful research domain for studying human problem solving and visual expertise also apply to Igo (Charness, 1992; Gobet, 1998; Burmeister, 2000). Relatively few studies have been conducted on the psychology of Igo-playing compared to chess, but it is attracting growing attention in the field of neuroscience and artificial intelligence (Yoshikawa and Saito, 1993; Yoshikawa et al., 1999; Burmeister, 2000; Bouzy and Cazenave, 2001; Chen et al., 2003; Ouchi et al., 2005; Takahashi et al., 2007).

Neural processes that support the ability to play the full game of Igo are unquestionably complex (Chen et al., 2003; Ouchi et al., 2005), but a set of problem-solving patterns at the corner of the board, called *shikatsu-mondai*, requires much simpler cognitive processes. The objective of *shikatsu-mondai* concerns making or preventing the opponent from making *nigan* (two eyes), which refers to the two-dimensional topology of stones that form two eyes such as in the figure of eight (Fig. 1C; see also Section 4.2). The visual concept of *nigan* is central to solving *shikatsu-mondai* because a group of stones that are connected to form *nigan* cannot be captured by the opponent and are thus warranted life. Notably, the fact that the “two-eye” pattern assures the life of stones is not a basic rule in Igo; rather, it is a key concept in the tactics of Igo that arises as a logical ramification of the rules (Fig. 1D). In other words, *nigan* is an ecologically meaningful visual pattern, recognition of which enables the player to solve *shikatsu-mondai* more efficiently with greater speed as compared to following the basic rules each time. The high speed with which advanced

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