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# Invariance detection in the brain: Revealed in a stepwise category induction task

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ABSTRACT

A critical sub-process of category learning is detecting the invariance between categorical members. To examine brain activation associated with invariance detection at different steps of category learning, a stepwise category induction task was used in the present study. Within each trial, three stimuli were displayed sequentially, and participants were asked to learn the target category corresponding to the invariance among stimuli. Results revealed that invariance detection activated the fronto-parietal network. However, the frontal and parietal cortices functioned differently throughout the different steps of invariance detection. The left middle frontal gyrus (BA 9) was highly activated in both steps of invariance detection, but the posterior parietal regions, especially the right superior parietal lobule (BA 7), were more active in the final step of invariance detection, reflecting increased attention to the completion of category learning and the preparation for a subsequent response. Furthermore, a psychophysiological interaction analysis (PPI) revealed increased connectivity between the left middle frontal gyrus and the bilateral parietal cortex during the final step of invariance detection. Overall, the present findings imply the necessary role of the fronto-parietal network in variance detection.



## 1. Introduction

Category learning, the ability to recognize category membership of sensory stimuli, is critical for interpreting the meaning of events and preparing adaptive responses (Swaminathan and Freedman, 2012). The neural mechanisms of category learning have been broadly explored using different tasks, including dot-pattern prototype learning, "cat–dog" categorization, and rule-based category learning (Freedman et al., 2001, 2002, 2003; Hammer et al., 2009, 2010; Jiang et al., 2007; Li et al., 2009; Meyers et al., 2008; Miller et al., 2003; Pan et al., 2008; Pan and Sakagami, 2012; Seger and Cincotta, 2006; Seger and Miller, 2010; Sloutsky, 2010; Smith, 2008). For example, in the morphing continuum of "cat–dog (A–B)" categorization tasks, humans and monkeys are trained to categorize morphed images from A and B into an A-like category or a B-like category. Findings have shown that the inferior temporal cortex (ITC) is more involved in the analysis of currently viewed shapes, while the prefrontal cortex (PFC) shows stronger category signals (Freedman et al., 2003; Jiang et al., 2007; Li et al., 2009). In rule-based category learning tasks, monkeys have been trained to apply either a "same" or "different" rule to novel pairs of pictures, and results suggest that

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PFC neurons reflect abstract rule-based categorical distinctions (Muhammad et al., 2006; Wallis et al., 2001; Wallis and Miller, 2003).

Most recently, some studies attempted to assess cortical responses to sub-processes involved in category learning. For example, Hammer et al. (2010) found that detecting between-category differences was associated with the dorsal striatum and hippocampus, while detecting within-category similarities and differences was restricted to high-level visual brain areas. Garcin et al. (2012) demonstrated that similarity detection involved the anterior ventrolateral PFC (VLPFC) bilaterally with a right–left asymmetry, while abstraction of categories activated the left dorsolateral PFC (DLPFC).

Although neural correlates of category learning have been explored through the aforementioned paradigms, the neural basis of invariance detection, the critical sub-process of category learning, remains unaddressed. Vigo (2013) suggested that detecting invariance patterns in categorical stimuli is a necessary precursor to concept formation.

The purpose of the present study was to examine brain activation associated with invariance detection by using a three-step category induction task (CIT), which was developed according to previous studies dealing with hypothesis testing or category induction (Bigman and Pratt, 2004; Bruner et al., 1956; Chen et al., 2007; Levine, 1975; Li et al., 2013). During this task, participants were sequentially presented three stimuli that belonged to the same category and were asked to learn the target category corresponding to the invariance among stimuli. There were three perceptual attributes for each stimulus, but only one kept invariance across the three stimuli during each trial, which had been predetermined by the experimenter. When the first stimulus (S1) was presented, participants identified and remembered three attributes of the stimulus, each of which might have been related to the target category. When the second stimulus (S2) was presented, participants needed to detect the invariance (two shared attributes) between S2 and S1 while filtering out the variant attribute. When the third stimulus (S3) was presented, participants needed to further detect the invariance between S3 and the preceding two stimuli while filtering out the new variance. However, during the baseline task (BT), perceptual dimensions did not change across the three stimuli. For example, all three letters might be black, uppercase, and diagonal. The perceptual encoding and comparison involved during the BT was the same as for the CIT, but processes inherent to category induction, especially the process of filtering out the variant or conflict attributes, were not required during the BT (Fig. 1).

Invariance detection is necessarily accompanied by the inhibition of variance information (Pan and Sakagami, 2012; Garcin et al., 2012). It has been found that filtering relevant information from irrelevant information activates the prefrontal and parietal cortices (McCabe et al., 2010; McNab and Klingberg, 2008; Gazzaley and Nobre, 2012). Accordingly, we expected the fronto-parietal network to be associated with invariance detection. Moreover, invariance detection occurred only during the presentation of the second (S2) and third stimuli (S3) (Fig. 1); thus, we assumed that the fronto-parietal network might be significantly activated during the last two steps (S2 and S3) when compared to the first step (S1).

## 2. Results

### 2.1. *Behavioral results*

Reaction time (RT) and accuracy data were recorded for each trial during the CIT and BT. Accuracy was defined as the percentage of correct responses out of the total number of

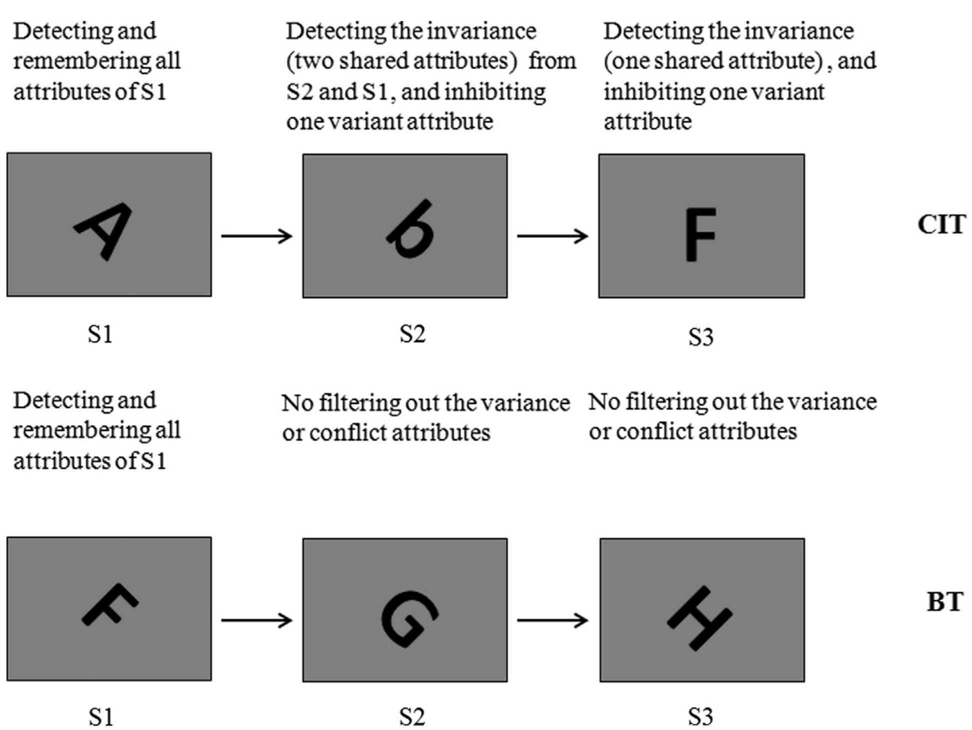


**Fig. 1 – Cognitive analysis used during the three steps of the category induction and baseline task.**