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Preserved implicit form perception and orientation adaptation in visual form agnosia

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Abstract

Visual form agnosia is mainly characterized by profound deficits in visual form and shape discrimination. Previous studies have shown that patients retain the capacity for coordinated motor behaviors, color naming and implicit letter perception. However, it is unknown to what extent other visual functions, such as implicit form and orientation perception, are preserved. To address these questions, we investigated a single visual form agnosic patient, X.F., in two distinct experiments. X.F.'s visual lesions were mainly localized in the bilateral occipitotemporal cortex, with the dorsal visual stream and early visual cortex largely spared. In Experiment 1, X.F. named the color of different forms across 12 blocks of trials. After the first six blocks, the combinations of a form with its color were changed and the new combination was presented for the remaining six blocks. X.F.'s reaction time increased during the switch block and was significantly greater than the overall RT changes between adjacent, non-switch blocks. This indicates that X.F. retained the ability to perceive changes in form despite her inability to discriminate the forms. In Experiment 2, X.F. showed selective orientation adaptation effects to different spatial frequencies; that is, her contrast threshold was significantly higher when the adapting and test orientations were the same than when they were orthogonal, although her orientation discrimination performance was severely impaired. These data provide evidence of a functional dissociation between explicit and implicit visual abilities, and suggest that the residual early visual cortex mediates form and orientation processing in the absence of awareness.

Keywords: Object recognition; Visual awareness; Lateral occipital area; Visual cortex

1. Introduction

In recent years, several case studies of visual form agnosia have been reported (e.g., Aglioti, Bricolo, Cantagallo, & Berlucchi, 1999; Benson & Greenberg, 1969; Campion & Latto, 1985; Sparr, Jay, Drislane, & Venna, 1991; for reviews, see Farah, 2004; Heider, 2000). Such patients are rare, but visual performance patterns and the location of brain lesions are similar across the reported cases. Visual form agnosia is mainly characterized by profound impairment in visual form and shape discrimination (Heider, 2000); however, these patients are able to recognize objects using other sensory modalities (e.g., auditory and tactile systems). Recent magnetic resonance imaging (MRI) (James, Culman, Humphrey, Milner, & Goodale, 2003) revealed that the major damage in D.F., an extensively studied case (Milner et al., 1991), is localized to the lateral occipital areas (LO) bilaterally, a region identified as important for object recognition (Grill-Spector, Kourtzi, & Kanwisher, 2001; Grill-Spector & Malach, 2004). In contrast, D.F.'s bilateral parietal cortex and primary visual cortex are largely intact.

Although visual form agnosia patients have severe visual dysfunctions, their visual abilities are not completely impaired. First, the patients retain the capacity for coordinated visuomotor behavior, which is associated with the dorsal visual stream (for reviews, see Goodale & Milner, 1992; Farah, 2004). Second, recent studies have shown that some visual functions mediated by the ventral stream are relatively spared in visual form agnosia, such as color perception, scene perception (Steeves et al., 2004) and implicit letter perception (Kentridge, Heywood, & Milner, 2004). For example, in a letter discrimination task (Aglioti et al., 1999), although a visual form agnosic patient, S.F., had impaired conscious letter recognition, accuracy was significantly higher during a Stroop task for presentation of color-congruent initial

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letters (e.g., "R" written in red color) than for color-incongruent letters. Using a similar single letter Stroop task, Kentridge et al. (2004) found significantly faster reaction times (RT) for congruent than for incongruent stimuli on correct trials in both color and letter discrimination tasks.

The Aglioti et al. (1999) and the Kentridge et al. (2004) studies indicate that visual form agnosic patients retain some ability to process letters, an ability that is largely dependent on the ventral visual stream. Considering that the early visual cortex is relatively intact in these patients, their findings suggest that this region may mediate implicit letter recognition. Neurophysiological recordings in animals and recent studies in humans have shown that the primary visual cortex (V1) participates in many kinds of visual perceptual processing, including orientation sensitivity (Haynes & Rees, 2005; He & MacLeod, 2001), shape identification (Humphrey et al., 1997; Sigman et al., 2005) and object recognition (Bar et al., 2001). Given such findings, it is plausible that although visual form agnosia patients are severely impaired in both form and orientation recognition (e.g., Campion & Latto, 1985; Milner et al., 1991; Sparr et al., 1991), they may be capable of processing related information using their relatively intact early visual cortex. In other words, it is important to clarify whether these patients can process form and orientation information implicitly, as has been reported for letter processing. Relatively preserved implicit processing would suggest that their visual impairment is mainly within the realm of explicit processing. We report two experiments investigating implicit form perception and orientation adaptation effects in a visual form agnosia patient, X.F. She had severe deficits in form and orientation discriminations, but performed relatively well in color and motion discriminations. In Experiment 1, X.F. named the color of different forms across 12 blocks of trials. After six learning blocks, the combination of a form with its color changed for the remaining presentations. The results showed that although form was irrelevant to the color naming task, X.F.'s RT increased when the color–form combination was switched. Moreover, the response inhibition induced by the change in form could not reflect a general change in performance, because the RT changes across the first six presentations were significantly smaller than those in the switch trial. In addition, although X.F. was impaired in a visual orientation discrimination task, in Experiment 2, after adaptation to a specific orientation, her contrast thresholds were higher for the adapted orientation than for the orthogonal. These data provide evidence of a functional dissociation between explicit and implicit visual abilities, and suggest that the early visual cortex mediates form and orientation processing in the absence of awareness.

2. Patient X.F.

2.1. Clinical history

X.F. is a right-handed, well-educated female. She was 42 years old when she participated in this study. X.F. suffered from carbon monoxide poisoning due to a fire in June 2000, 2 years before our examination. She could open her eyes unconsciously 2 days after fire, and regained consciousness after 20 days. X.F.'s most prevalent complaint was an inability to see objects and people clearly, although she was able to identify familiar people by their voices or statures. Strikingly, when playing table tennis with other people, X.F. was able to hit the ball back and forth over 10 times consecutively. She also retained the ability to perform everyday tasks such as dressing, eating, opening doors and avoiding obstacles. X.F.'s spontaneous speech was normal, and she was able to understand others easily. However, X.F. lacked motivation to initiate goal-directed behavior, and developed compulsive behavior in daily life, which manifested as a repetitive wiping of the nose.

Structural MRI scans (T1 weighted fast spin-echo inversion recovery sequence) collected in April 2002 revealed that X.F. had neocortex lesions in the bilateral occipitotemporal and anterior frontal cortices (see Fig. 1), together with enlarged ventricles. The ventral occipitotemporal lesions included the bilateral area LO and the posterior part of the fusiform gyrus. The LO lesions appeared larger in the left hemisphere than the right. Her early visual cortex, including primary visual cortex, was relatively intact. In the dorsal visual stream, part of the left posterior parietal cortex was damaged, but other parts of the parietal cortex exhibited no obvious damage.

2.2. Visual function

X.F. performed a series of neuropsychological tests between April and November 2002. Two healthy female subjects matched to X.F. for age and educational level also participated in these tests. Table 1 lists the visual performance characteristics of X.F., and of other reported cases of visual agnosics for comparison (Aglioti et al., 1999; Benson & Greenberg, 1969; Campion & Latto, 1985; Milner et al., 1991; Sparr et al., 1991). As described below, we employed same/different discrimination tasks to test and characterize X.F.'s visual perceptual function for parameters such as brightness, orientation, spatial frequency, color, motion, form perception and object recognition. During test trials of a given visual feature, all non-tested visual features remained constant. For each task, stimulus pairs were presented in random order, with equal numbers of same and different trials (except brightness and color discrimination tasks, see below). Each pair remained on the computer screen until the subject responded. To further distinguish discrimination sensitivity from the decision criterion (Hannula, Simons, & Cohen, 2005), d' was calculated, defined as the Z-score difference between hit and false alarm rates (Macmillan & Creelman, 1991).

2.2.1. Visual fields and eye movements

Examination of X.F.'s visual fields with static perimetry (diameter = 64 mm^2) revealed ranges of approximately 90° horizontally and 70° vertically, with no hemianopia observed in either field. An infrared sensing device was used to test eye movements. X.F. was able to follow the instruction to move her eyes to a target and fixate on the stimulus for approximately 1 s. Although her vertical saccades were somewhat restricted, horizontal saccades were intact.