Functional modulation of contralateral bias in early and object-selective areas after stroke of the occipital ventral cortices

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ABSTRACT

Object agnosia is a rare symptom, occurring mainly after bilateral damage of the ventral visual cortex. Most patients suffering from unilateral ventral lesions are clinically non-agnosic. Here, we studied the effect of unilateral occipito-temporal lesions on object categorization and its underlying neural correlates in visual areas. Thirteen non-agnosic stroke patients and twelve control subjects performed an event-related rapid object categorization task in the fMRI scanner where images were presented either to the left or to the right of a fixed point. Eight patients had intact central visual fields within at least 10° eccentricity while five patients showed an incomplete hemianopia. Patients made more errors than controls for both contra- and ipsilesional presentation, meaning that object categorization was impaired bilaterally in both patient groups. The activity in cortical visual areas is usually higher when a stimulus is presented contralaterally compared to presented ipsilaterally (contralateral bias). A region of interest analysis of early visual (V1–V4) and object-selective areas (lateral occipital complex, LOC; fusiform face area, FFA; and parahippocampal place area, PPA) revealed that the lesioned-hemisphere of patients showed reduced contralateral bias in early visual areas and LOC. In contrast, literally no contralateral bias in FFA and PPA was found. These findings indicate disturbed processing in the lesioned hemisphere, which might be related to the processing of visually presented objects. Thus, unilateral occipito-temporal damage leads to altered contralateral bias in the lesioned hemisphere, which might be the cause of impaired categorization performance in both visual hemifields in clinically non-agnosic patients. We conclude that both hemispheres need to be functionally intact for unimpaired object processing.

1. Introduction

Visual object agnosia describes the inability to recognize visually presented objects and occurs mostly as a consequence of bilateral damage of the ventral visual cortex (Goodale et al., 1991; Karnath et al., 2009; Delvanne et al., 2004; Farah, 2004; Valdés-Sosa et al., 2011). However, cases of visual agnosia (e.g. prosopagnosia) have also been observed after unilateral cortical lesions (Barton, 2008; Konen et al., 2011; Anaki et al., 2007; Landis et al., 1986). Visual agnosia can be divided into two broad subclasses (Lissauer, 1890): apperceptive agnosia involves deficits at the perceptual (pre-categorical) level of visual processing, while in visual associative agnosia patients show difficulties with assigning semantic information to a visually presented object. Unilateral lesions of occipito-temporal cortex do not generally cause major object recognition deficits. Nevertheless, when damage to brain areas occurs within the ventral stream there may be a disruption of object processing networks affecting object processing capacities, thus causing at least subtle object recognition deficits (Behemmann and Plaut, 2013; Martinaud et al., 2012). Conversely, intact areas probably compensate for functionally impaired object processing by means of reorganization processes (Leonard et al., 2009; Neltes et al., 2002; Tsapkini et al., 2011).

Object agnosia is usually diagnosed on the behavioral level using bedside cognitive tests, such as naming objects, supplying semantic information about objects, and drawing objects (Greene, 2005). These tests predominantly unveil major deficits of object perception or identification potentially owing to the fact that object stimuli are presented centrally. However, a unilateral lesion may cause only unilateral (contralateral) object recognition deficits, leaving the recognition of an ipsilesionally presented object unaffected due to lateralized stimulus processing in the cortical visual system. Central objects will be processed both in the intact and the lesioned hemisphere and hence, the intact hemisphere may compensate for subtle object recognition deficits. To overcome this problem, we presented objects laterally in order to distinguish between objects presented ipsi- versus contralesionally.

Contrary to other agnosia studies, the aim of the current study is not to differentiate between subclasses of agnosia in patients...
apparent object recognition deficits, but to find subtle changes in object recognition in patients without apparent signs of agnosia. We used a rapid categorization task that was simple and demanding enough to unveil general subtle object recognition deficits (Thorpe et al., 1996). To successfully categorize objects, two processes are crucial: the detection of the object (which would be pre-categorical) and its classification to its corresponding category (which requires at least some identification process). This means that pure sensory information alone is insufficient for categorization (Delorme et al., 2010; Wichmann et al., 2010) yet it is possible to categorize the object without complex higher cognitive processes (such as attention or language). An fMRI study revealed that, as well as higher (such as FFA and PPA) visual areas are activated in rapid categorization (Fize et al., 2000), indicating processing on the sensory as well as on the perceptual level. A rapid categorization task has been previously used in a patient with apperceptive agnosia and is hence suitable for clinical populations (Boucart et al., 2010). Due to brief presentation time, the task is sensitive in terms of processing speed as subtle changes in object perception may occur when processing time is limited. Our aim was to investigate patients after unilateral infarction of the occipito-temporal cortices for general object recognition deficits that might selectively occur in the contralesional visual field.

In visual areas of healthy subjects, the activation to contralateral stimulation is usually higher compared to the activation to ipsilateral stimulation, which can be seen as a contralateral bias. It is well known that striate and extrastriate visual areas are involved in different aspect of visual information processing, such as region V1 deals with orientation, contrast and colour (Hubel and Wiesel, 1959); V2 with figure-ground segregation, binocular disparity and illusory contours (Hubel and Livingstone, 1987); V3 with integration of visual modalities, such as colour and motion (Gigenfurter et al., 1997); and V4 with size constancy and colour processing (Tanaka and Fujita, 2015). Moreover it is also well known that these “early” visual areas contain a retinotopic representation of the contralateral visual hemifield (e.g. Horton and Hoyt, 1991). When stimulated, the visual hemifield elicits higher activation in the contralateral than in the ipsilateral hemisphere; and when the early visual cortex is damaged, it causes homonymous visual field defects. In addition, higher visual object processing areas, such as the lateral occipital complex (LOC), fusiform face area (FFA) and parahippocampal place area (PPA), also show a preference for the contralateral bias in higher visual object processing areas has been observed in electrophysiological (de Op Beeck et al., 2000; Sato, 1989) as well as functional magnetic resonance imaging (fMRI) studies in healthy populations (Hemond et al., 2007; Large et al., 2008; McKynon and Zohary, 2007; Niemeier et al., 2005; Sayres and Grill-Spector, 2008). After a stroke of the ventral visual cortex, neural activity in object processing areas may be altered, possibly affecting contralateral bias. A changed contralateral bias might thus reflect impaired functionality after unilateral brain damage, and lesioned and intact hemispheres may be differently affected. We used contralateral bias as an indicator of altered brain dynamics in defined object processing brain areas of stroke patients.

The present study was driven by two main questions: 1) Do specific chronic, clinically non-agnosic patients show impaired performance in a lateralized object categorization task? 2) Are there activation patterns in object related cortical areas correlated to intact versus deficient performance, and is the processing in early visual areas intact in these patients?

Patients and healthy controls were presented with natural scene images that either did or else did not contain an animal while lying in the fMRI scanner. All images were briefly presented to the left or to the right of a central fixation point. We hypothesized that patients would show impaired object categorization performance for contralesionally presented images. This would be accompanied by lower activation to contralesional stimuli in both hemispheres (because of transcallosal connections). Since we expect normal activation to ipsilesional stimuli, a reduced contralateral bias was expected in the lesioned hemisphere, in other words: less activation to contralesional stimuli, but normal activation to ipsilesional stimuli in patients. Accordingly, we also expected that the intact hemisphere might show an elevated contralateral bias. If patients were not impaired in object categorization, we expected neural compensation processes, such as higher activation in the intact hemisphere for contralesional stimulus presentation.

In summary, we investigated the influence of unilaterally damaged object processing networks on object categorization with images presented laterally. We tested whether the intact hemisphere is sufficient for completely intact object processing. We expected that activation changes after damage to brain areas within the object processing network may shed light on the general function of the ventral visual stream.

2. Methods

2.1. Subjects

In total, fourteen chronic stroke patients with unilateral damage to the occipito-temporal cortex (age range: 46–74 years, mean age: 59 ± 10 years) and 12 healthy controls (age range: 40–71 years, mean age: 58 ± 11 years) participated in this study. One patient who suffered from a quadrantanopia was unable to see the stimuli in the contralesional hemifield and was excluded from analysis. The remaining 13 patients were at three months poststroke minimum (range: 3 months–3 years; mean: 1.5 ± 1.2 years). Inclusion criteria for patients were 1. unilateral stroke to the occipital and/or temporal cortex (lesions additionally extending to the parietal cortex were also included), 2. no clinically observable agnosia, which was examined by using neuropsychological tests such as the Fragmented Picture Test, Rey-Osterrieth Complex Figure Test, object naming, and subjective object recognition deficits (Table 1), and 3. patients with free visual fields (no visual field defects within the central 10 degrees in standard perimetry); patients with quadrantanopia or incomplete hemianopia were included when they were able to see and react to the stimuli (Fig. 1). Patients with complete homonymous hemianopia were excluded. Visual fields were evaluated by using standard automatic static perimetry. One patient obtained kinetic instead of static perimeter (patient 1, see Fig. 1). The criterion for visual field defect in static perimetry (within 10 degrees of eccentricity) was fulfilled when three adjacent test-stimuli were below the age-related normal values in both eyes. Analyses revealed that despite being able to see and react to the lateralized stimuli, response patterns of patients with visual field defects differed from patients with intact visual fields. Therefore, we treated these patients groups separately: patients with intact visual field (iVF) and patients with defective visual field (dVF). Eight patients had intact central visual fields (within 10°) while five patients showed scotomas (quadrantanopia or incomplete hemianopia). Exclusion criteria were cognitive impairments such as dementia, neglect, ophthalmological disorders such as glaucoma or macular degeneration and severe neurological or psychiatric disorders. All subjects had normal or corrected-to-normal visual acuity. Two patients showed very small additional lesions contralateral to the main lesion (Patient 1: frontal left, Patient 2: occipital left). Nevertheless, they were treated as unilaterally lesioned patients. Three patients suffered additionally from cerebellar infarction (Patient 2 and 8 and 12). All subjects gave informed written consent in accordance with procedures approved by the local ethical committee of Bremen University, Germany.

2.2. Scanning

2.2.1. General

We used a 3 T head-only Siemens Allegra MRI scanner with a
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