Vision Research 50 (2010) 1074–1085

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Top-down projections to the primary visual areas necessary for object recognition: A case study

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ARTICLE INFO

Article history:
Received 12 January 2009
Received in revised form 21 January 2010

Keywords:
Visual agnosia
Object recognition
Global versus local processing
Top-down versus bottom-up processes

ABSTRACT

We present a patient, who, following a right posterior ischemia, showed a selective deficit in visually recognising pictures, objects and faces. She was able to read and comprehend any kind of written material and could recognise letters and numbers. Her inability to recognise pictures did not arise from a deficit at the structural description level and/or from a poor semantic knowledge of the stimuli. We argue that her recognition deficit arose from an inability in combining the different elements of the visual stimuli in an unitary percept. Results are discussed in terms of dissociations between local versus global processing, as well as bottom-up versus top-down mechanisms.

1. Introduction

There is general consensus now that the separate features of the stimulus, such as shape, colour, movement and depth are differently processed by specialised cells for each dimension (Ackroyd, 2003; Cowey, 1985; Humphreys & Riddoch, 1987; Vaina, Solomon, Chowdhury, Sinha, & Belliveau, 2001; Zeki, 1993; Zihl, Von Cramon, & Mai, 1983). However, despite this huge amount of data, little is known about the mechanisms which generate the perception of a coherent world where the different dimensions of the objects are tied together to form unitary percepts. The behaviour of some agnosic patients seems very relevant to the issue of this binding process. When shown an object or picture they cannot recognise, some agnosics frequently guess its identity on the basis of its local parts or features. This behaviour lends itself to interpretation in terms of a hierarchical system of shape representation, whose lower stages are relatively intact but whose higher levels of integration are damaged or unavailable. Riddoch and Humpreys (1987) have explicitly suggested that such an impairment may underlie certain cases of agnosia, and they introduced the term "Integrative Agnosia" for such cases. In Humphreys and Bruce's model (1989), Integrative Agnosia arises from a damage at a stage where the different properties of the stimulus (such as colour, depth, length and magnitude) are combined in a unique global structure. In their model, the automatic and parallel elaboration of the different sensorial properties of the stimulus (such as line orientation, colour, magnitude and depth) activates a subsequent stage (the stage for the localisation and integration of the elementary object's properties) where object identification could be achieved either through its global form or through the elaboration of its distinct properties. Humphreys and Riddoch (1987) used the term "Shape Agnosia" for patients whose impairment is caused by damage at the global shape process. These patients selectively fail to perform tasks, such as tracing the object's contours, matching elementary geometric forms or copying them and discriminating simple geometric shapes (e.g., a circle or a square). In these cases, all the different object categories are compromised (objects, faces, letters) (Efron, 1968; Milner et al., 1991). For example, the patient D.F., extensively described by Milner and Goodale (e.g. James, Culham, Humphreys, Milner, & Goodale, 2003; Milner & Goodale, 1995), who suffered severe bilateral damage to her occipito-temporal visual system, was unable to indicate the size, shape and orientation of an object despite her preserved ability to use those information to control her grasping movements.

On the contrary, patients who suffer from "Integrative Agnosia" demonstrate incapability to put together object properties. They are selectively unable to integrate the object's different details, as they are incapable of translating the local information into a unique global structure. Studies of patients with object recognition disorders showed that this process of shape integration can be selectively damaged even when elementary object's features processes operate normally. Moreover, stored knowledge about objects can be preserved in patients with poor shape integration.

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doi:10.1016/j.visres.2010.03.018

Riddoch and Humpreys (1987) illustrated this deficit in an agnosic patient with occipital bilateral lesions (H.J.A.), who succeeded on shape discrimination and shape-copying tasks, but failed on more stringent tests of visual perception such as detecting targets embedded in displays of homogeneous distractors. Riddoch and Humpreys (1987) argued that H.J.A. was impaired in integrating shape elements into perceptual wholes. They termed this disorder 'Integrative Agnosia'. H.J.A. could accurately draw pictures from memory demonstrating an intact stored knowledge of objects and he could also copy objects he could not identify. However, his ability to identify visually presented objects was markedly disrupted: the subject, who is able to recognise the different parts of an object, is incapable of putting them together in a unitary percept (Behrmann & Kimchi, 2003; De Renzi & Lucchelli, 1993; Grossmann, Galetta, & D'Esposito, 1997; Ricci, Vaishnavi, & Chatterjee, 1999).

The difficulty in part–whole synthesis becomes even more apparent when the stimulus includes multiple internal segmentation cues; for example, Integrative agnosic patients typically find more difficult to recognise objects that overlap one another than when the same items are presented in isolation. In contrast, when the task does not require features integration the performance is generally well preserved. For example, patients typically show intact performance in the discrimination of line length, line orientation, size judgements, spatial localisation of dots, colour and motion processing (Behrmann & Kimchi, 2003; De Renzi & Lucchelli, 1993; Grossmann, Galetta, & D'Esposito, 1997; Humphreys & Riddoch, 1987; Ricci et al., 1999; Riddoch & Humpreys, 1987).

Lesion information is also available for patients with Integrative Agnosia. In most instances resulting from stroke, bilateral posterior lesions are reported (Allen, Humphreys, & Bridge, 2007; Grossmann, Galetta, & D'Esposito, 1997; Riddoch, Humphreys, Gannon, Blott, & Jones, 1999). Generally, cases with Integrative Agnosia appear to have bilateral ventral lesions, with the lesions also tending to encroach into the posterior temporal lobes (Riddoch et al., 2008). Conversely, the "shape agnosic" patient D.F. showed a more diffuse cortical lesions which included the bilateral ventral lateral-occipital cortex, sparing the primary visual cortex (James et al., 2003).

Studies on object processing have revealed that not only the different stages of recognition but also our stored knowledge about the different classes of visual objects (objects, faces and words) can be fractionated. Farah (2004) argued that there are two main processes underlying visual recognition: a global process, which may be carried out by the right hemisphere, and an analytical one, which elaborates the different parts of the object relying on the left hemisphere. Faces depend on the processing of non decomposed holistic representations; whereas, words undergo decomposition into many parts, and their recognition occurs only through the identification of the multiple parts. Object processing can involve both processes depending on the degree of deficit. According to these observations, it is not possible to disrupt object recognition selectively without affecting either face or word recognition (Farah, 2004).

Classical physiological studies of visual cortex confirm the hypothesis that visual recognition is performed by a hierarchy of stages which activate different cortical areas in the ventral stream (Barone, Batardiere, Knoblauch, & Kennedy, 2000; Hochstein & Ahissar, 2002; Lerner, Hendler, Ben-Bashat, Harel, & Malach, 2001). Neurons of low-level areas (V1, V2) receive visual input and detect simple features, such as lines or edges of specific orientation and location. Output from low-level areas are then integrated and processed by successive cortical levels (V3, V4, medial-temporal area MT), which gradually generalise over spatial parameters and specialise in representing global features. Finally, further levels (inferotemporal area IT, prefrontal area PF, etc.) integrate their outputs to represent forms, objects and categories. However, from anatomical studies it is also clear that cortico-cortical connections not only run from lower areas to higher ones (bottom-up, B-U), but also in the reverse direction (Salin & Bullier, 1995). These top-down fibres (T-D) provide feedback signals that may play a role in object recognition as well. For example, it has been hypothesised that these feedback signals are necessary to process spatially detailed information (Hochstein & Ahissar, 2002). In this framework, feedforward processing involves rapid and automatic processes that provide basic object categorizations, yet incorporating a limited amount of details. For a complete representation, higher areas would need to reach back to the low-level areas by means of cortical feedback mechanisms (Hochstein & Ahissar, 2002; Lee, Mumford, Romero, & Lamme, 1998; Roelfsema, Lamme, & Spekreijse, 2000; Sugase, Yamane, Ueno, & Kawano, 1999). Roelfsema et al. (2000) have argued that contour tracing depends on feedback from higher level regions in ventral cortex (e.g., area V4) to primary visual cortex, so that tracing can operate across larger regions than those typically covered by the receptive fields of neurons in primary visual areas.

Recordings from different levels of the cortical hierarchy during recognition show minor latency differences ($\sim$10 ms), suggesting that during the subsequent recognition process there can be interaction of B-U, T-D, and lateral information flow (Hupé et al., 1998; Lamme, 1995; Lamme & Roelfsema, 2000).

Attention is another type of feedback that places priority in the information to be analysed and makes perception purposeful. In a simplified view, attention can be considered as a window (Broadbent & Broadbent, 1990; Nakayama, 1991; Van Essen, Olshausen, & Gallant, 1991) that is moved either by eye movements or by "covert" processes that occur without eye movement (Posner, Snyder, & Davidson, 1980). It has been suggested that attention imposes a ring of inhibition around an attended item in order to ignore unnecessary competing objects to better reach an unambiguous, single visual interpretation. Evidence has been found by using imaging methods to study primary visual areas mechanisms, both in human (Smith, Singh, Williams, & Greenlee, 2001) and monkey (Tootell et al., 1998; Vanduffel, Tootell, & Orban, 2000).

The biased competition model (Desimone & Duncan, 1995; Reynolds & Desimone, 1999) proposes that visual stimuli compete to be represented by cortical activity. Competition may occur at each stage along a cortical visual information processing pathway. The outcome of this competition is influenced not only by bottom-up, sensory-driven activity, but also by top-down, attention-dependent biases. These top-down influences increase the amplitude and duration of the generated neural activity in response to an attended stimulus and thus affects the on-going competition between cells (Luck, Chelazzi, Hillyard, & Desimone, 1997; Reynolds & Desimone, 1999). Hence, top-down information, originating from a wide range of different sources, can potentially modulate neural activity and can bias competition (Hupé et al., 1998; Lamme, Supèr, Landman, Roelfsema, & Spekreijse, 2000; Lee et al., 1998).

Our study attempts to analyse the nature of object recognition difficulty in an unilateral right temporo-occipital damaged patient who was totally unable to visually recognise objects and faces despite her good semantic knowledge and good performance in reading letters and words. To assess her abilities, several tests were administered. The particular contribution of local versus global information and bottom-up versus top-down processes to the recognition process are considered.

2. Case report

FP is a 46-year-old right-handed female graduate in Political Science who was well until July 2005 when a massive infarction re-