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Visual object and face processing in mild-to-moderate Alzheimer's disease: from segmentation to imagination

Lynette J. Tippett [a,*], Kirsty Blackwood [a], Martha J. Farah [b]

[a] *Department of Psychology, University of Auckland, Private Bag 92019, Auckland, New Zealand*
[b] *University of Pennsylvania, Philadelphia, PA, USA*

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Abstract

Little is known about the fate of higher level visual perception and visual mental imagery in the early stages of Alzheimer's disease (AD). In this study, we assessed these abilities in a group of mild-to-moderate AD patients using tasks selected to satisfy two main criteria. First, they have been shown to be sensitive to impairments of perception and imagery caused by other neurological conditions. Second, they test specific stages of visual perception and cognition in a reasonably selective manner. These stages were (in their normal order of occurrence during perception): the segmentation of different local points of the visual field into regions belonging to distinct objects; the representation of the shapes of these segmented regions in the image; the construction of more abstract shape representations that possess constancy over changes in size, location, orientation or illumination (assessed separately for faces and objects); the use of these perceived shape representations to access stored shape representations; and the access of lexical semantic representations from these high-level visual representations. Additional tasks tested the top–down activation of earlier visual representations from the semantic level in visual mental imagery. Our findings indicate small, but in most cases reliable, impairments in visual perception, which are independent of degree of cognitive decline. Deficits in basic shape processing influenced performance on some higher level visual tasks, but did not contribute to poor performance on face processing, or to the profound deficit on object naming. The latter of these is related to semantic-lexical impairment.

Keywords: Visual perception; Object recognition; Mental imagery; Alzheimer disease

1. Introduction

Visual stimuli are normally encoded at multiple levels within the visual system, and neurological disease and injury may interrupt this process at any stage. Damage beyond primary visual cortex can therefore result in a spectrum of disorders. At relatively early stages, the segmentation of the image into regions corresponding to candidate objects or object parts can be impaired, resulting in an apperceptive agnosia (e.g. [5]). At later levels, the construction of a structural description of object shape may be impaired, and this impairment may disproportionately affect faces or common objects (e.g. [28,49]). At the endpoint of visual object recognition, semantic and lexical knowledge concerning the object is accessed. These stages can also be impaired by brain damage (e.g. [64]). Finally, semantic memory knowledge may be used to reinstantiate earlier visual representations in a process known as mental image generation, and this, too, can be impaired in neurological patients (e.g. [23]).

The goal of this article is to determine whether Alzheimer's disease (AD), in its mild-to-moderate form, typically affects these intermediate and higher levels of visual perception or visual imagery, and to localize any impairments found along the spectrum just described. The evidence currently available on visual perception in Alzheimer's disease does not allow us to answer these questions.

Tasks involving high-level vision and object recognition are often impaired in the early stages of AD. Difficulty with confrontation naming, for example, is an early and characteristic sign of the disease. Of course, this task requires semantic and lexical processing as well as visual object recognition, and AD patients are generally thought to fail for this reason (e.g. [37,43,50]).

AD patients are also impaired on several nonverbal tasks involving high-level vision, but here too the underlying cause of the impairment is ambiguous. For example, in some studies, poor performance on the Picture Arrangement subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R) has been noted, and the possibility has been

* Corresponding author. Tel.: +64-9-3737-599x8551; fax: +64-9-3737-450.
E-mail address: l.tippett@auckland.ac.nz (L.J. Tippett).

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discussed that object recognition deficits are at least partially to blame (e.g. [14,15,41]). Although the task does involve recognizing a number of line drawings, it also places significant demands on executive functions, including sequencing and abstraction. Visuospatial tasks such as Block Design (a subtest of the WAIS-R), and copying the Rey Complex Figure are also sensitive to AD (e.g. [4,31,44,54]). These tasks are free of semantic content, yet they often involve a constructional element, and are also known to be sensitive to executive functions which again may themselves be compromised in AD (e.g. [48]).

Studies that systematically isolate visual processing in AD patients have mostly focussed on early levels of visual perception, such as colour vision, stereoacuity, contrast sensitivity and susceptibility to backward masking (e.g. [3,14,16,17,56,66]). Although certain impairments have been documented at these early levels, they do not necessarily imply that higher levels of perception will be impaired. People can be color blind, have poor acuity, or even lack stereovision, but have no trouble with higher levels of perception such as object recognition.

Two recent studies have examined higher levels of visual perception in AD. Giannakopoulos et al. administered several tests involving visual perception and object recognition to patients with relatively advanced AD, and correlated their performance with the types and distributions of neuropathological changes found at autopsy. For present purposes, their results demonstrate that visual perception may be severely compromised at later stages of the disease. However, we cannot infer whether these deficits began to emerge at an earlier stage, before the more global effects of the disease were manifest. In addition, the tests themselves combined a number of levels and types of visual processing, in some cases involving semantic knowledge as well.

Kurylo et al. [41] selected four clinical neuropsychological tasks associated primarily with visual processing for object recognition (Mooney Closure Faces, Face Recognition Test, WAIS-R Picture Arrangement, Discrimination of Complex Pictures) and four associated primarily with visual processing for spatial perception (Mental Rotation task, Money-Road-Map Test, Stick Test, Discrimination of Spatial Position test), and administered them to a sample of mild-to-moderately impaired AD patients. They found impaired performance on all tasks, significantly more pronounced for the visual object perception tasks. Their results were interpreted in terms of the framework of “two cortical visual systems” [60], and they do indeed suggest differential degradation of object, relative to spatial, vision. However, a finer-grained characterization of the impairment, within the visual object perception system, is not possible given the tasks used or on the basis of the results.

Higher level visual and spatial perception in patients with mild AD was also assessed by Binetti et al. [7,8] using the Visual Object and Space Perception battery [63]. This study is closest in spirit to the one we report, in that it utilized tasks from the cognitive neuropsychology literature that are intended to tap different stages of vision in a relatively selective way. In contrast to Kurylo et al. [41], these researchers found a slight impairment in spatial functioning when scores from all four spatial tasks were combined, but their subjects did not differ from controls over the four visual perception tasks. It is possible that this null result simply reflects the very early stage of the disease in their patients. It is also possible that a different and larger set of tasks, that distinguished different stages of visual perception with more specificity, would increase the sensitivity of such a research project.

In overview, the main aim of this study was to use such a set of tasks, which have been shown to tap different stages of intermediate and higher levels of visual perception and visual imagery with reasonable specificity. To clarify the logic of task selection a brief review of the different stages of visual processing, including what we know about the brain regions associated with each stage and the nature of impairments corresponding to deficits of each stage, is outlined below.

1.1. Image segmentation

After the initial registration of local features of the visual field including color, contour, depth, motion and so forth, the image must be segmented. In other words, locations in the visual field which are likely to belong to a single object must be grouped together, and segmented away from locations likely to belong to other objects. We identified two tasks in the neuropsychological literature that tax this ability in particular: The Shape Detection task from the Visual Object and Space Perception Battery (VOSP) [63] and the Shape Perception task described by Efron [21]. These tasks are described in detail in Section 2.

Image segmentation has been dissociated from the perception of local visual features in the syndrome of apperceptive agnosia. While apperceptive agnosics are able to perceive local features of the visual field such as brightness, color, motion, and line orientation, they can not recognize even the most basic of shapes, nor letters, objects, or faces (e.g. [5,21,42]). The neural substrates of image segmentation are difficult to deduce from apperceptive agnosia as it is almost always the result of carbon monoxide poisoning or anoxia, which result in diffuse structural brain damage. Single cell recordings in monkeys, however, indicate that neurons crucial to the segmentation process appear as early as V2 and certainly in V4. For example, there are neurons in V2 that respond to illusory contours (e.g. [61]) and cells in V4 with large, silent surrounds adjacent to the excitatory or classical RF that respond maximally only when the stimulus stands out from its background on the basis of a difference in features such as form, wavelength, and spatial frequency [19].

1.2. Shape constancy

A segmented image is a kind of shape representation, in that it describes the shapes of regions in the picture plane,