Neuropsychologia 100 (2017) 64–78

Contents lists available at ScienceDirect

Neuropsychologia

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

Developmental visual perception deficits with no indications of prosopagnosia in a child with abnormal eye movements

Sharon Gilaie-Dotan[a,b,*], Ravid Doron[c,d]

[a] Department of Optometry and Visual Science, Bar Ilan University, Ramat Gan, Israel
[b] UCL Institute of Cognitive Neuroscience, London, UK
[c] Department of Optometry and Vision Science, Hadassah Academic College, Jerusalem, Israel
[d] Goldschleger Eye Research Institute, Sackler Faculty of Medicine, Tel-A viv University, Tel-Hashomer, Israel

ARTICLE INFO

Keywords:
Object recognition
Contour integration
Geometry
Eye movements
Pursuit
Saccades
Developmental visual agnosia
Face perception

ABSTRACT

Visual categories are associated with eccentricity biases in high-order visual cortex: Faces and reading with foveally-biased regions, while common objects and space with mid- and peripherally-biased regions. As face perception and reading are among the most challenging human visual skills, and are often regarded as the peak achievements of a distributed neural network supporting common objects perception, it is unclear why objects, which also rely on foveal vision to be processed, are associated with mid-peripheral rather than with a foveal bias.

Here, we studied BN, a 9 y.o. boy who has normal basic-level vision, abnormal (limited) oculomotor pursuit and saccades, and shows developmental object and contour integration deficits but with no indication of prosopagnosia. Although we cannot infer causation from the data presented here, we suggest that normal pursuit and saccades could be critical for the development of contour integration and object perception. While faces and perhaps reading, when fixated upon, take up a small portion of central visual field and require only small eye movements to be properly processed, common objects typically prevail in mid-peripheral visual field and rely on longer-distance voluntary eye movements as saccades to be brought to fixation. While retinal information feeds into early visual cortex in an eccentricity orderly manner, we hypothesize that propagation of non-foveal information to mid and high-order visual cortex critically relies on circuitry involving eye movements. Limited or atypical eye movements, as in the case of BN, may hinder normal information flow to mid-eccentricity biased high-order visual cortex, adversely affecting its development and consequently inducing visual perceptual deficits predominantly for categories associated with these regions.

1. Introduction

Many regions in high order visual cortex show category-specific sensitivity such as to faces, places, words, common objects, and body-parts (Malach et al., 1995, 2002; Kanwisher et al., 1997; McCarthy et al., 1997; Epstein and Kanwisher, 1998; Gauthier et al., 2000; Kourtzi and Kanwisher, 2000; Downing et al., 2001, 2006; Grill-Spector et al., 2001; Levy et al., 2001; Cohen et al., 2002; Dehaene et al., 2002; Hasson et al., 2002; Pitcher et al., 2009; Konen et al., 2011). Furthermore, lesion studies, electrophysiological recordings, microsimulation and TMS studies indicate that the integrity and activation in some of these regions are critical for the perception of these categories. For example, regions in the right fusiform are critical for face perception (Barton et al., 2002; Parvizi et al., 2012; Behrmann and Plaut, 2013, 2014; Gilaie-Dotan et al., 2013c; Rangarajan et al., 2014), the left fusiform for word perception (Sekuler and Behrmann, 1996; Behrmann et al., 1998; Behrmann and Plaut, 2014; Habekost et al., 2014), the lateral occipital complex/cortex (LOC), especially in the right hemisphere, for object perception (Milner and Goodale, 1993; James et al., 2003; Konen et al., 2011; Gilaie-Dotan et al., 2013c, 2015) and parahippocampal cortex for scene perception (Epstein et al., 2000). Until recently the organizational principles guiding the sensitivities in high-order visual cortex remained elusive; it is now clear that eccentricity guides not only retinotopic cortex, but also high-order visual cortex organization. For example, faces and words are associated with foveally biased regions (Levy et al., 2001; Hasson et al., 2002; Malach et al., 2002; Weiner et al., 2014), places with peripherally biased regions (Levy et al., 2001, 2004; Weiner et al., 2014), and common objects with mid-peripheral bias (Hasson et al., 2002, 2003; Sayres and Grill-Spector, 2008). The association of faces and words with a foveal

* Corresponding author at: Department of Optometry and Visual Science, Bar Ilan University, Ramat Gan, Israel.
E-mail address: shagido@gmail.com (S. Gilaie-Dotan).

http://dx.doi.org/10.1016/j.neuropsychologia.2017.04.014
Received 22 August 2016; Received in revised form 3 April 2017; Accepted 7 April 2017
Available online 09 April 2017

bias seems intuitive given that foveal vision is required for their perception. Also intuitive is the association of places and houses with peripheral bias given the spatial integration required for place perception (Levy et al., 2004). However, the association of objects with mid-peripheral bias in high-order visual cortex remains unclear.

Neuropsychological and visual neuroscience have debated whether faces, common objects and words are supported by a joint (as a distributed) processing network (Ishai et al., 1999a; Haxby et al., 2001; Avidan et al., 2002; Behrmann and Plaut, 2013, 2014) or by more modular category-specific regions or networks (Kanwisher et al., 1997; Epstein and Kanwisher, 1998; Downing and Kanwisher, 1999; Kanwisher, 2000; Downing et al., 2001; Spiridon and Kanwisher, 2002; Schwarzlose et al., 2005; Baker et al., 2007; Germine et al., 2011; Pitcher et al., 2012; Susilo et al., 2013, 2015). Intermediate proposals of a joint network for faces and objects or for words and objects are also supported by lesions adversely affecting multiple categories ((Behrmann et al., 1994; Moscovitch et al., 1997; Gilaie-Dotan et al., 2013c) and see (Farah, 2004) for review). While the evidence is complex and this debate is far from being resolved, the idea that objects, that are associated with mid to peripheral bias in high order visual cortex, would be jointly processed within the same network as faces or as words, that are each associated with a foveal bias, is somewhat puzzling.

Eye movements have long been implicated in visual perception (Yarbus, 1967; Noton and Stark, 1971a, 1971b; Martinez-Conde et al., 2004; Schutz et al., 2011), and much more so in visual attention (e.g. (Corbetta et al., 1998; Torralba et al., 2006; Rolfs et al., 2011). For example, Yarbus showed that different eye movement patterns are associated with different visual perceptual categories (e.g. faces, outdoor woods (Yarbus, 1967)), and it has also been shown that eye movements are attracted to salient features of the visual scene, such as animals, contours, or visual motion (Rolf et al., 1998; Krieger et al., 2000; Itti, 2005; Guyonneau et al., 2006; Kirchner and Thorpe, 2006; Bacon-Mace et al., 2007). Yet, how critical eye movements are for the development of normal visual perception has not been widely addressed.

Here we report on our investigation of BN, a 9 y.o. boy, whose face (and person) perception skills provide no indication of prosopagnosia. However, BN has significant perceptual deficits that are most evident but not limited to animals, geometry, and contour integration. Interestingly, he also shows abnormal eye movements as limited pursuit and imprecise saccades. Following these findings we discuss the possibility that pursuit and saccade eye movements play a significant role in the development of normal object and geometry perception.

2. Case history

BN is a bright and intelligent 9 year old boy, studying at school at his age level (in the Israeli general education system). He receives special education support in school to improve his gross and fine motor skills, and to assist in overcoming his perceptual difficulties. For a certain period he also attended occupational therapy to overcome his graphomotor problems. His parents reported that despite his normal basic level vision, he experienced many visual perceptual difficulties (some of which persist), and also difficulties in placing himself and manipulating objects in the environment. They recalled that he was unable to assemble simple puzzles of four pieces and did not play with toy blocks. In school BN experiences severe difficulties in geometry, a subject which he fails in, in contrast to his normal or above normal performance in math. They also recalled he would hold a cup obliquely or would not usually stand in the “appropriate” place in a queue or elevator. Until the age of five he was unable to distinguish between common fruits (e.g. apple and plum), whereupon his mother explicitly taught him these distinctions using children’s picture booklets and verbal explanations. BN has animal recognition impairments; he can confuse a dog and a cat, he thought a nearby ostrich was a cow, and that a big dog he saw in the park was a tiger. His visual perception may at times be “fragmented”; when shaking hands with someone, he reported perceiving the other person’s arm separated from their body. These observations and incidents, recalled by his parents, fit findings by a number of developmental specialists that examined BN (see details below). We present here a synopsis of their findings.

At the age of five, a *psychologist* diagnosed BN as having visual perception deficits, difficulties distinguishing between figure and ground, and not scanning a picture as expected.

At the age of 5.8 (years.months notation), *clinical educational psychologists* administered the Hebrew version of the Wechsler Preschool and Primary Scale of Intelligence (*WPPSI* (Lieblich, 1971)) to BN. His verbal score was 106 (categorized as Average) and his performance score was 71 (categorized as Borderline), leading to a total score of 88 (Low Average). The verbal score was based on his scores in the following subtests (each subtest has a mean of 10 and a standard deviation of 3): general knowledge (scored 8), vocabulary (scored 13), math (scored 11), common-side (measuring verbal abstraction, scored 13), and comprehension (measuring practical intelligence knowledge, scored 10). The performance score was based on his scores in zoo locations (scored 7), picture completion (scored 7), mazes (fine motor and spatial planning, scored 7), geometric shapes (scored 2), and block design (scored 6) subtests.

At the age of 6 a *psychiatrist* diagnosed BN with “fragmentation” after BN drew a person with scattered body parts.

During that period (age 5–6), a *psychologist* and a *psychiatrist* diagnosed BN with difficulties in graphomotor and visuomotor movements, sensory modulation, and in assembling puzzles, yet with normal language comprehension, general knowledge and mathematics.

2.1. Earlier basic visual functions assessments

At the age of 7.11, a visual screening examination by an *optometrist* at his school showed that BN’s distance visual acuity (VA) was normal (5/5) in both eyes.

At the age of 8.4, an *expert orthoptist* examined BN’s basic level vision and found orthophoria present (i.e. normal balance between the eye muscles permitting lines of sight to meet at the point of fixation), and no strabismus. Distance VA in each eye was 6/6. Normal convergence and accommodation were found. Binocular vision measures were normal: normal depth perception, positive fusion range, and normal binocular vision. The orthoptist observed difficulties in pursuit eye movements during the ocular motility test.

In a hearing test (audiology examination) at the age of 6, BN showed normal hearing in both ears. He also showed normal hearing at an auditory screening test at school.

3. Current study

We met BN and his family to examine his visual perception and function, and consequently to consider possible means for alleviating some of his visual deficits. Here we report the findings from the examinations that started when BN was 9.0 and continued until he was 9.4. The study was approved by the Sheba Medical Center Helsinki committee. BN’s parents agreed to his participation in the study and signed a consent form. A concise summary of the findings, described in detail below, is given in Table 1.

3.1. Oculomotor assessments

3.1.1. Standard clinical tests for evaluating pursuit and saccades

We started our examination by focusing on the orthoptist’s predominant finding, BN’s difficulties in pursuit and saccades.

3.1.1.1. General procedures. The Northeastern State University College of Optometry (NSUCO) Oculomotor test (Maples and Ficklin, 1988;