The role of parvocellular and magnocellular shape maps in the derivation of spatially integrated 3D object representations in human vision

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RUNNING HEAD: Commentary on Vannuscorps et al. (in press)

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Our ability to effectively process visual information necessitates the transformation of sensory input from retinotopic to non-retinotopic representations of scene content. One fundamental question concerns the mechanisms, types of representation, and coordinate systems, that mediate these transformations. The complexity of their interactions makes this a formidable challenge.

Davida's case presents with a highly specific deficit affecting the mapping between representations of sensory input based on retinotopic coordinates and higher-level non-retinotopic reference frames. To account for her performance, the authors outline a theoretical proposal that makes several important claims. Among those are: (1) the existence of a level of intermediate shape-centred representation (ISCRs - or 'shape maps') that mediates the mapping between retinotopic and body-centred/spatiotopic representations of scene content; (2) the parallel derivation of independent ISCRs encoding object shape information via parvocellular (P-cell) and magnocellular (M-cell) channels. Davida's impairment is assumed to arise from a selective deficit affecting the mapping between the proposed ISCR and body-centred/spatiotopic reference frames in the P-cell channel. This interesting proposal invites further speculation about the possible role of the proposed ISCRs in the derivation of spatially integrated representations of complex 3D object shapes – and their prospective role in object recognition. The question we discuss here is how this proposal might link to other recent work about the structure and functional organisation of object shape representations in human vision.

A growing body of evidence suggests that object representation in human vision is hierarchical, decompositional, and parts-based (e.g., Behrmann & Kimchi, 2003; Behrmann, Peterson, Moscovitch & Satoru, 2006; Biederman, 1987; Hoffman & Richards, 1984; Leek, Reppa & Arguin, 2005; Leek, Reppa, & Tipper, 2003; Reppa & Leek, 2003; Robertson & Lamb, 1981). These multi-level representations comprise elementary local features (e.g., edges and vertices), intermediate-level functional units (e.g., spatially bounded 2D regions approximating visible surface structure - Leek,

Reppa & Arguin, 2005; Reppa, Greville & Leek, 2015; Marr & Nishihara, 1978; Palmer & Rock, 1994), and (on some accounts) higher-order primitives such as volumetric parts (e.g., Biederman, 1987; Marr & Nishihara, 1978). Evidence for this complex decompositional representational structure comes from both studies of neurologically intact, and brain-damaged, individuals. For example, there are case reports of patients with acquired object recognition impairments who have difficulty distinguishing among 3D objects that comprise the same geometric parts arranged in different 3D spatial configurations (e.g., Behrmann & Kimchi, 2003; Behrmann et al., 2006); studies showing complementary patterns of local-global feature representation deficits following unilateral brain lesions (Robertson & Lamb, 1981), and parts-based object identification errors associated with so-called integrative agnosia (e.g., Humphreys & Riddoch, 1987; Leek, Patterson, Paul et al., 2012). Other work has shown that the derivation of representations of 3D objects involves parallel processing of shape information at multiple spatial scales across local and global image content (e.g., Davitt, Cristino, Wong et al., 2018; Leek, Roberts, Dundon et al., 2018; Leek, Roberts, Oliver et al., 2016; Pegna, Darque, Roberts et al., 2018).

So how might this evidence about the functional organisation of complex 3D object representations fit with the theoretical proposal outlined by Vannuscorps et al (in press), and with the pattern of performance in found in Davida? Of potential relevance to these questions is the model outlined by Bar and colleagues (e.g., Bar, 2003; Bar, Kassam, Ghuman et al., 2006; Kveraga, Boshyan & Bar, 2007 – see also Laycock, Crewther & Crewther, 2007 for a related idea). According to this model, object recognition involves recurrent parallel processing along two processing pathways: Slow, high contrast/high spatial frequency analyses of fine detail mediated by P-cell channels along ventral occipitotemporal cortex; and fast, low contrast/low spatial frequency analyses of coarse global shape mediated by M-cell channels via orbitofrontal cortex. The fast, low contrast, analyses of coarse global shape structure is assumed to facilitate recognition by providing recurrent top-down constraints on the derivation of structured (spatially integrated) object representations. In support of this proposal, Kveraga et al (2007) have shown differential activation of the M- and P-cell pathways during an image

classification task involving low contrast, achromatic, 'M-biased' versus chromatically defined, isoluminant (red-green), 'P-biased' stimuli.

There are interesting similarities between these two proposals that seem to merit further investigation. On the one hand, one might predict that a deficit affecting the mapping between the hypothesised P-cell ISCR shape maps and higher-order reference frames – as proposed for Davida, would have 'downstream' consequences for the derivation of spatially integrated object representations. This follows from the assumption that P-cell and M-cell channel information must be integrated across spatial scales, at some level of representation, into structured 3D shape descriptions. More specifically, in the case of Davida, one might predict that during the derivation of these spatially integrated representations there is a loss of information about fine (high contrast) local detail (via P-cell channels) and a relative preservation of coarse (low contrast) global structure (via M-cell channels). This seems consistent with Davida's difficulty in correctly computing the orientation of high contrast, but not low contrast, shape stimuli.

At the same time, a striking aspect of her performance profile is the apparent lack of impairment in object identification. It is tempting to speculate that the preservation of information flow through the M-cell channel ISCRs may be sufficient to support object identification – at least for certain kinds of stimuli (as well as other aspects of her performance including preserved orientation judgements for low-contrast defined 2D and 3D stimuli). Here it is perhaps relevant to note the relatively limited range of shape stimuli that Davida has been tested on which are largely restricted to simple object forms (e.g., letters, line drawings and abstract shapes). In contrast, the proposed deficit in Davida might be expected to cause problems for the integration of shape information across spatial scales during the derivation of more complex 3D object representations – which remains to be seen. Thus, to the extent that the perception of complex 3D objects requires the integration of ISCRs across spatial scales (that is, the integration of shape-centred maps across P-cell and M-cell channels), we might also expect Davida to show impairments in recognition tasks that require the discrimination of

shape in terms of local (P-cell) rather than global (M-cell) image structure (e.g., Behrmann et al, 2003;

2006; Kveraga et al, 2007; Oliver et al, 2018).

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