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The occipital place area represents the local elements of scenes

Frederik S. Kamps [a], Joshua B. Julian [b], Jonas Kubilius [c], Nancy Kanwisher [d], Daniel D. Dilks [a,*]

[a] Department of Psychology, Emory University, Atlanta, GA 30322, USA
[b] Department of Psychology, University of Pennsylvania, Philadelphia, PA 19104, USA
[c] Laboratories of Biological and Experimental Psychology, Faculty of Psychology and Educational Sciences, KU Leuven, Leuven, Belgium
[d] Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

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ABSTRACT

Neuroimaging studies have identified three scene-selective regions in human cortex: parahippocampal place area (PPA), retrosplenial complex (RSC), and occipital place area (OPA). However, precisely what scene information each region represents is not clear, especially for the least studied, more posterior OPA. Here we hypothesized that OPA represents local elements of scenes within two independent, yet complementary scene descriptors: spatial boundary (i.e., the layout of external surfaces) and scene content (e.g., internal objects). If OPA processes the local elements of spatial boundary information, then it should respond to these local elements (e.g., walls) themselves, regardless of their spatial arrangement. Indeed, we found that OPA, but not PPA or RSC, responded similarly to images of intact rooms and these same rooms in which the surfaces were fractured and rearranged, disrupting the spatial boundary. Next, if OPA represents the local elements of scene content information, then it should respond more when more such local elements (e.g., furniture) are present. Indeed, we found that OPA, but not PPA or RSC, responded more to multiple than single pieces of furniture. Taken together, these findings reveal that OPA analyzes local scene elements – both in spatial boundary and scene content representation – while PPA and RSC represent global scene properties.

Introduction

Functional magnetic resonance imaging (fMRI) studies have reliably identified three scene-selective regions in human cortex: the parahippocampal place area (PPA) (Epstein and Kanwisher, 1998), the retrosplenial complex (RSC) (Maguire, 2001), and the occipital place area (OPA) (Dilks et al., 2013), also known as transverse occipital sulcus (TOS) (Grill-Spector, 2003) (Fig. 1). However, precisely what information each region extracts from scenes is far from clear—particularly for the least studied OPA.

More is known about information processing in face- and body-selective cortical systems. In face processing, the more posterior occipital face area (OFA) responds strongly to face parts (i.e., eyes, nose, mouth) regardless of their spatial arrangement, whereas the more anterior fusiform face area (FFA) represents face parts and the typical spatial arrangement of these parts (e.g., two eyes above a nose above a mouth) (Yovel and Kanwisher, 2004; Pitcher et al., 2007; Liu et al., 2009). Similarly, among body-selective regions, the more posterior extrastriate body area (EBA) represents body parts, with the response to body parts rising gradually as more of the body is visible (e.g., a single finger versus a hand with five fingers). By contrast, the more anterior fusiform body area (FBA) is sensitive to the whole body, not the amount of body shown (Taylor et al., 2007). Here we ask whether the scene processing system exhibits a similar functional division of labor. In particular, we hypothesize that the more posterior OPA represents scenes at the level of local elements, while the more anterior PPA and RSC represent the global properties of scenes.

But what are the local elements of a scene? Initial clues can be found in behavioral and computational work suggesting that scenes are represented by two independent, yet complementary descriptors: i) *spatial boundary*, or the external shape, size, and scope of the space, and ii) *scene content*, or the internal features of the scene encompassing objects, textures, colors, and materials (Oliva and Torralba, 2001, 2002). Within spatial boundary representation, local scene elements may be the major surfaces and planes that together comprise the spatial boundary (i.e., walls, floors, and ceilings). Evidence for this possibility comes from the finding that PPA responds significantly more to images of intact, empty apartment rooms than to these same rooms in which the walls, floors, and ceilings were fractured and rearranged, such that they no longer defined a coherent space (Epstein and Kanwisher, 1998). This possibility also dovetails with one approach in robotic mapping that assumes that elements of the environment consist of large, flat surfaces (e.g., ceiling and walls) (Thrun, 2002). Next, within scene content representation, local scene elements may be the individual objects, textures, colors, and materials that make up the internal content of a scene (Oliva and Torralba, 2001, 2002). For example, a piece of furniture

* Corresponding author at: Department of Psychology, Emory University, 36 Eagle Row, Atlanta, GA 30322, USA.
E-mail address: dilks@emory.edu (D.D. Dilks).

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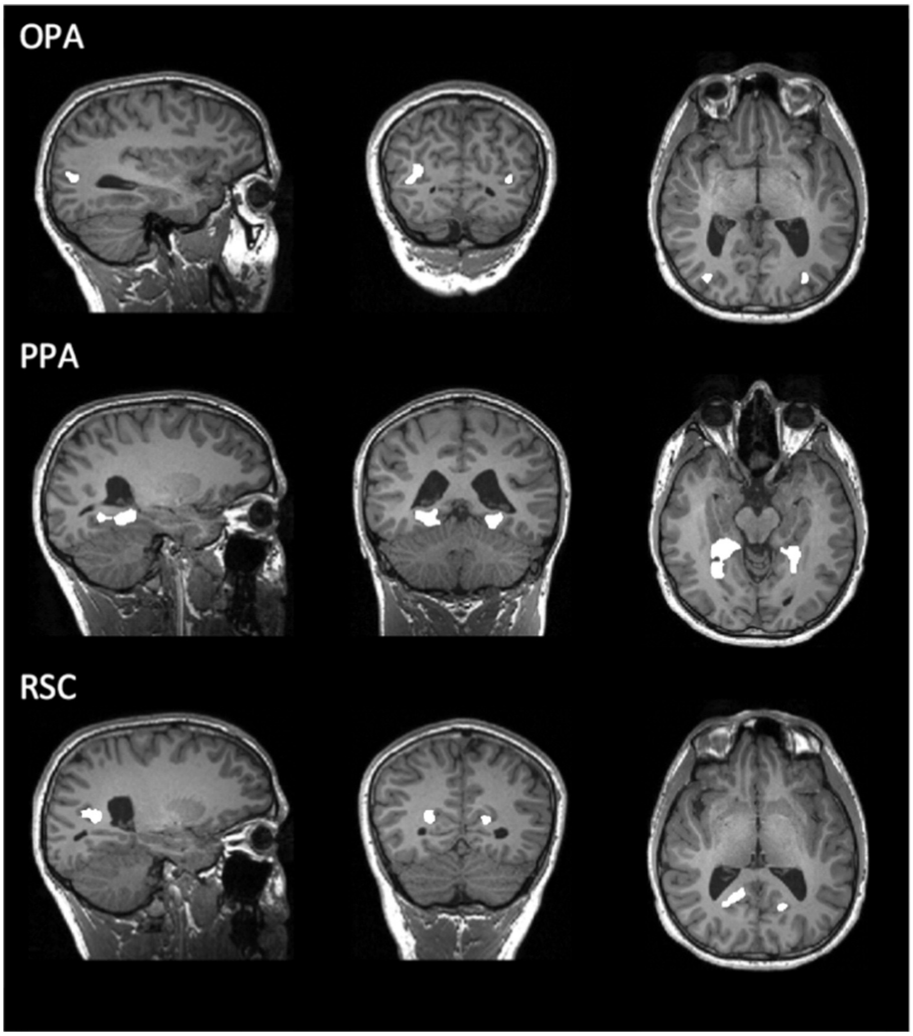

Fig. 1. Scene-selective regions of interest (ROIs) in a sample participant. Occipital Place Area (OPA), Parahippocampal Place Area (PPA), and Retrosplenial Complex (RSC), labeled accordingly. Using 'Localizer' runs, these ROIs were selected as those regions responding significantly more to scenes than objects ($p < 0.0001$, uncorrected). Responses of these ROIs to the experimental conditions were then tested using an independent set of data (Experimental runs).

might be considered a local scene element insofar as furniture is an object that is typically associated with particular places or contexts (e.g., a sofa is typically found in a living room) (Bar and Aminoff, 2003), and is different from other 'objects' because it is generally large and not portable (Mullally and Maguire, 2011; Konkle and Oliva, 2012; Troiani et al., 2014).

To test whether the more posterior OPA represents local scene elements within both spatial boundary and scene content representation, we examined responses in OPA (as well as PPA and RSC) to images of 1) empty rooms; 2) these same rooms 'fractured' and rearranged such that the walls, floors, and ceilings no longer defined a coherent space; 3) single, nonfurniture objects; 4) single pieces of furniture; and 5) multiple pieces of furniture (Fig. 2). Within spatial boundary representation, if the more posterior OPA processes scenes at the level of local elements, then it should not represent the coherent spatial arrangement of the elements, but rather the local elements themselves. As such, we predicted that OPA would respond similarly to the empty and the fractured rooms. By contrast, if the more anterior PPA and RSC encode global representations of the spatial boundary, then they should respond more to images of empty rooms that depict a coherent layout than to images of fractured and rearranged rooms in which the spatial boundary is disrupted. Within scene content representation, if OPA is sensitive to the local elements of scenes (i.e., furniture), then it should respond more when more such elements are presented. As such, we predicted that OPA would respond more to images of multiple pieces of furniture than to images of single pieces of furniture. By contrast, if PPA and RSC represent global properties of scene content, then their responses should be independent of the amount of content (i.e., furniture) presented.

Methods

Participants

Twenty-five participants (Age: 18–25; 12 from Emory University, 13 from MIT; 13 females, 12 males) were recruited for this experiment. Two participants were excluded from further analyses because of nonsignificant localizer results, and one for excessive motion during scanning, yielding a total of 22 participants reported here. All participants gave informed consent and had normal or corrected-to-normal vision.

Design

We used a region of interest (ROI) approach in which we localized category-selective regions (Localizer runs) and then used an independent set of runs to investigate their responses to a variety of stimulus categories (Experimental runs). For both Localizer and Experimental