



Research report

Perceived egocentric distance sensitivity and invariance across scene-selective cortex

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ABSTRACT

Behavioral studies in many species and studies in robotics have demonstrated two sources of information critical for visually-guided navigation: sense (left-right) information and egocentric distance (proximal-distal) information. A recent fMRI study found sensitivity to sense information in two scene-selective cortical regions, the retrosplenial complex (RSC) and the occipital place area (OPA), consistent with hypotheses that these regions play a role in human navigation. Surprisingly, however, another scene-selective region, the parahippocampal place area (PPA), was not sensitive to sense information, challenging hypotheses that this region is directly involved in navigation. Here we examined how these regions encode egocentric distance information (e.g., a house seen from close up versus far away), another type of information crucial for navigation. Using fMRI adaptation and a regions-of-interest analysis approach in human adults, we found sensitivity to egocentric distance information in RSC and OPA, while PPA was not sensitive to such information. These findings further support that RSC and OPA are directly involved in navigation, while PPA is not, consistent with the hypothesis that scenes may be processed by distinct systems guiding navigation and recognition.

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1. Introduction

The navigability of a scene is completely different when mirror reversed (e.g., walking through a cluttered room to exit a door either on the left or right), or when viewed from a proximal or distal perspective (e.g., walking to a house that is either 50 feet or 500 feet in front of you). Indeed, behavioral evidence has demonstrated that both sense (left-right) and egocentric distance (proximal-distal) information are used in navigation by insects (Wehner, Michel, & Antonsen, 1996), fish (Sovrano, Bisazza, & Vallortigara, 2002), pigeons (Gray, Spetch,

Kelly, & Nguyen, 2004), rats (Cheng, 1986), rhesus monkeys (Gouteux, Thinus-Blanc, & Vauclair, 2001), and humans (Fajen & Warren, 2003; Hermer & Spelke, 1994). Similarly, studies in robotics highlight the necessity of sense and egocentric distance information for successful visually-guided navigation (Schöner, Dose, & Engels, 1995). The term navigation has been defined by the above studies and many other reports as a process of relating one's egocentric system to fixed points in the world as one traverses the environment (Gallistel, 1990; Wang & Spelke, 2002). Here we use this standard definition of navigation.

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A recent fMRI adaptation study (Dilks, Julian, Kubilius, Spelke, & Kanwisher, 2011) found sensitivity to one of the two critical types of information guiding navigation (i.e., sense information) in two human scene-selective cortical regions, the retrosplenial complex (RSC) (Maguire, 2001), and the occipital place area (OPA) (Dilks, Julian, Paunov, & Kanwisher, 2013), also referred to as the transverse occipital sulcus (Grill-Spector, 2003), consistent with hypotheses that these regions play a direct role in human navigation (Dilks et al., 2011; Epstein, 2008; Maguire, 2001). By contrast, another scene-selective region, the parahippocampal place area (PPA) (Epstein & Kanwisher, 1998), was not sensitive to sense information, challenging hypotheses that this region is directly involved in navigation (Cheng & Newcombe, 2005; Epstein & Kanwisher, 1998; Ghaem et al. 1997; Janzen & van Turenhout, 2004; Rauchs et al. 2008; Rosenbaum, Ziegler, Winocur, Grady, & Moscovitch, 2004; Spelke, Lee, & Izard, 2010). Here we investigate how these regions encode egocentric distance information (e.g., a house seen from close up versus far away), another type of information crucial for navigation. Given that RSC and OPA are sensitive to sense information – one type of information that is crucial for navigation – we predict that these regions will also be sensitive to egocentric distance information. By contrast, since PPA is not sensitive to sense information, we predict that this region will also not be sensitive to egocentric distance information.

To test our predictions, we used an event-related fMRI adaptation paradigm (Grill-Spector & Malach, 2001) in human adults. Participants viewed trials consisting of two successively presented images of either scenes or objects. Each pair of images consisted of one of the following: (1) the same image presented twice; (2) two completely different images; or (3) an image viewed from either a proximal or distal perspective followed by the opposite version of the same stimulus. If scene representations in scene-selective cortex are sensitive to egocentric distance information, then images of the same scene viewed from proximal and distal perspectives will be treated as different images, producing no adaptation across distance changes in scene-selective cortex. On the other hand, if scene representations are not sensitive to egocentric distance information, then images of the same scene viewed from proximal and distal perspectives will be treated as the same image, and the neural activity in scene-selective cortex will show adaptation across egocentric distance changes. We examined the representation of egocentric distance information in the three known scene-selective regions (PPA, RSC, and OPA) in human cortex.

2. Methods

2.1. Participants

Thirty healthy individuals (ages 18–54; 17 females; 26 right handed) were recruited for the experiment. All participants gave informed consent. All had normal or corrected to normal vision. One participant was excluded for excessive motion, and another participant did not complete the scan due to claustrophobia. Thus, we report the results from 28 participants.

2.2. Design

We localized scene-selective regions of interest (ROIs) and then used an independent set of data to investigate the responses of these regions to pairs of scenes or objects that were identical, different, or varied in their perceived egocentric distance. For the localizer scans, we used a standard method described previously to identify ROIs (Epstein & Kanwisher, 1998). Specifically, a blocked design was used in which participants viewed images of faces, objects, scenes, and scrambled objects. Each participant completed 3 runs. Each run was 336 sec long and consisted of 4 blocks per stimulus category. The order of the stimulus category blocks in each run was palindromic (e.g., faces, objects, scenes, scrambled objects, scrambled objects, scenes, objects, faces) and was randomized across runs. Each block contained 20 images from the same category for a total of 16 sec blocks. Each image was presented for 300 msec, followed by a 500 msec interstimulus interval (ISI). We also included five 16 sec fixation blocks: one at the beginning, three in the middle interleaved between each palindrome, and one at the end of each run. Participants performed a one-back task, responding every time the same image was presented twice in a row.

For the experimental scans, participants completed 8 runs each with 96 experimental trials (48 ‘scene’ trials and 48 ‘object’ trials, intermixed), and an average of 47 fixation trials, used as a baseline condition. Each run was 397 sec long. On each fixation trial, a white fixation cross (subtending $.5^\circ$ of visual angle) was displayed on a gray background. On each non-fixation trial, an image of either a scene or an object was presented for 300 msec, followed by an ISI of 400 msec and then by another image of the same stimulus category presented for 300 msec – following the method of Kourtzi and Kanwisher (2001) and many subsequent papers. After presentation of the second image, there was a jittered interval of ~ 3 sec (ranging from 1 to 6 sec) before the next trial began. Each pair of images consisted of one of the following: (1) the same image presented twice (Same condition); (2) two completely different images (Different condition); or (3) an image viewed from either a proximal or distal perspective followed by the opposite perspective of that same image (Distance condition) (Fig. 1A). In total, each subject viewed 128 trials of each condition (Same, Different, Distance). Note, in the Distance condition, we were careful to manipulate only perceived egocentric distance information, while not changing the angle from which the scenes were viewed. To ensure that viewing angle did not change between the Distance conditions in our stimuli, we first identified the same point in both the proximal and distal perspectives of each image (e.g., a window) and measured its distance (in pixels) away from two other points (to the right and left) in each image (e.g., fence posts). Next, we calculated the ratio of the distance from the central point and the point on the left to the distance between the central point and the point on the right, and finally, compared the ratios between the two perspectives. We found no difference in viewing angle between the near and far images of scenes [mean ratio: near = 2.35, far = 2.33; $t_{(9)} = .25$, $p = .81$]. Further, there were equal numbers of trials in which a proximal image preceded a distal image, and vice versa. This aspect of the experimental design is important because it

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