Dispatch

Human Navigation: Occipital Place Area Detects Potential Paths in a Scene

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Navigation — determining how to get from where you are to somewhere else — has obvious importance for the survival of motile animals. A new neuroimaging study has revealed that, in the human brain, the occipital place area detects the number of possible paths in a vista.

Henri Poincaré proposed that space is best understood in terms of how we interact and move within it [1]. This idea was formalized by Gibson with his theory of affordances — characterising the actions that can be taken in a given environment, based on what we perceive, as well as our knowledge of what we expect [2]. For example, when we first move to a new neighborhood, we may stick to the larger, more direct roads to go in to work, but as we explore the environment, we find alternative routes and the available options expand. Over time, when we step out from our house, the scene in front of us has transformed in terms of how we may interact with it, yet its sensory properties are unchanged. The physical structure of most visual scenes is generally invariant, and does not change radically over time, leading to statistically predictable regularities of contexts which help in guiding object and scene identification [3]. Most research on scene perception has focused on how attention is directed to various aspects of the scene, based on both bottom-up features, such as visual saliency [4] or spatial arrangement [5], and top-down sources such as semantic categories [6] or memories [7]. To date, little has been done to merge what we know about scene perception and navigation. In a recent study, Bonner and Epstein [8] tackle the question of how prospective movement options in the environment are represented in the brain, paving the way for furter studies exploring the interaction between externally imposed boundaries for locomotion and goal-directed navigation.

Using an elegant and highly controlled design, Bonner and Epstein [8] first asked whether any previously identified scene-selective brain areas — the parahippocampal place area(PPA), retrosplenial complex (RSC) or occipital place area (OPA) [9] —respond to available options for actions (navigational affordances), such as pathways leading out of a room. In the first experiment, artificial scenes were created, with three walls and up to three potential visible exits (doors), the number of which was varied across scenes. Additionally, to control for low-level visual differences in scenes with and without exits, there were stimuli in which the potential exits were blocked by a painting, thus looking visually similar, but offered reduced navigational possibilities. Importantly, the task performed by participants was unrelated to navigation or the properties of the scenes' affordances. Using representational similarity analysis (RSA), a method for quantifying functional magnetic resonance imaging (fMRI) activation patterns in the brain, the authors identified areas that responded more similarly when the direction and number of exits amongst various scenes overlapped.

Bonner and Epstein [8] found that only activity in the OPA showed a significant correlation between scenes with similar navigational affordances (Figure 1); the PPA and RSC, areas that respond to scenes in general, did not distinguish navigational affordances. This effect was replicated in a second experiment in which more complex natural scenes were used (though here, the PPA also significantly coded affordances). Furthermore, a univariate analysis examining overall neural activity (as opposed to activity patterns) in the OPA showed an increase with the number of doorways, but this effect disappeared when looking at scenes with equivalent visual complexity but reduced navigational affordances (those with paintings blocking exits). These results indicate that the OPA distinguishes between scenes that differ on the amount and direction of visible exits, and is independent of general low-level saliency and gist-based features, which might be expected if the OPA were coding simpler, non-navigationally specific features of the scene.

An impressive aspect of the new study [8] was the use of an encoding model to reconstruct navigational affordances in a new set of scenes, based on the neural activity patterns elicited from an independent training set. Briefly, brain activity patterns for a single scene image from all subjects were combined across each region-of-interest, then principal components were extracted representing the shared variance across subjects for that scene. Navigational affordance maps were created for each image, based on paths drawn by an independent group of participants. A linear decoder was trained on one half of the scenes [10], using the pixel-wise affordance information in the scene and resulting voxelwise activity in the principal components. The reconstruction model was then run on the remaining unseen set of images to predict a two-dimensional heatmap of navigational affordances of the image based on brain activity. The signal in the OPA was used to reliably reconstruct the veridical paths in the scenes, indicating selective coding of navigational aspects of scenes, independently of their semantic content and other navigationally irrelevant visual properties. This implies that based on the OPA fMRI data alone, the researchers would be able to predict the navigational affordances of a scene just viewed, an exciting prospect for artificial intelligence applications that need to predict human behavior in an environment.

The results seemingly unseat the king of scene selective areas, the PPA, a much more established region implicated in navigation [11]. However, Bonner and Epstein [8] point to recent results implicating the PPA in landmark identity [12], which may increase the specificity with which the PPA encodes affordances, making it less flexible to changes in overall scene identity (this fits in with analyses showing that changes in textures, a proxy for identity, in the artificial scenes reduced the similarity representation in PPA for equivalent affordances). Moreover, the OPA is well placed in the dorsal visual stream to be involved in visuospatial perception and visuomotor processing [13], and has recently been implicated as necessary for processing boundaries in visual scenes [14,15]. Boundaries are a central tenet to navigational behavior [16], and processing potential pathways may be intricately linked to those borders.

The next steps are to explore how these brain patterns relating to navigational affordances are modulated by actual goal-directed navigation. We know that long-term memories bias perception and attention to certain locations in scenes [17], so how might these affordances change with learning or exposure to the environment? Additionally, topological aspects of the environment are coded in the hippocampus and frontal cortex [18], but it is unclear how that information may be immediately available to the OPA without learning. This raises the issue as to whether the OPA is a simple detector of movement options in a scene, which is relayed to downstream areas in the medial temporal lobe, or whether its activity is modulated by known, but currently invisible aspects of the environment. Over a hundred years after the original proposal, this study has opened up the path for studying navigation in terms of ecological affordances and understanding the involvement of the visual system in this fundamental ability.

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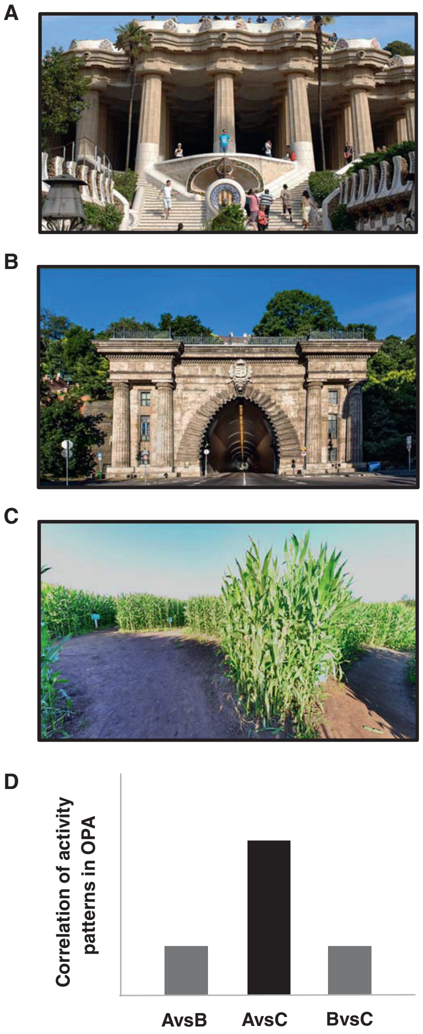

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Figure 1. The OPA codes for the number and direction of navigational affordances in a scene, independently of visual complexity.

The stairs in Park Guell (A) and the Cornfield in Alabama (C) both contain two paths, whereas the Tunnel in Budapest (B) offers only one direction of movement: although image B is more complex than either A or C, it has lower navigational affordance. The graph (D) shows how the patterns of activity in the OPA [8] are more similar for image A and C than for any other pairing.

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