Dispatch

Object perception in the cortex: Where do we see the weight?

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A new study examining the response of the human brain as subjects view objects of different weights that they are about to lift has provided novel insights into the division of labour between two major subdivisions of the visual system: the dorsal and ventral streams. These are often considered to be responsible for the visual control of actions towards objects and object identification respectively. The new result shows that the weight of objects, which influences the way we act upon them, is nevertheless represented in the ventral visual stream.

Milner and Goodale's [1] hypothesis that the processing of visual information in the cerebral cortex can be both anatomically and functionally divided into two components has proved both influential and controversial. They suggested that information leaving primary visual cortex along projections travelling to the parietal lobe, the dorsal stream, is used for the visual control of action towards objects, whereas information passing from striate cortex through the temporal lobe, the ventral stream, is used in identifying objects. A new study in this issue of *Current Biology* [2] reports important findings suggesting that properties of objects that influence the manner in which actions operate upon them can be represented in areas of the ventral stream. Specifically, the study shows that areas within the ventral stream respond selectively to objects with different weights independently of their responses to the visual properties of those objects. Crucially, visual information influences the force applied to objects before lifting action itself starts and so this component of action must be determined by the visual properties of the object rather than simply being a response to kinaesthetic feedback. Of course, the weight of an object cannot be inferred directly from visual properties of objects, but we easily learn to associate visual properties with weight – after a little experience we know by looking that a Styrofoam cup is lighter than a China one. By using objects that look identical but which subjects learn have different weights in one experiment, and objects that look as if they should be heavy, but which subject learn are light (and vice versa) in a second experiment, Gallivan and his colleagues show that weight and the visual properties that are cues to weight, such as texture, are represented independently within areas in the ventral stream.

The study used multivoxel pattern analysis of fMRI signals [3] in order to determine the areas of cortex in which expectations about the weight of objects were represented. Unsurprisingly, weight influences the pattern of activity in primary motor cortex as the object is lifted. The critical findings are that expectations of weight, either derived from repeated experience of lifting a specific object or from associations between the surface properties (colour and texture) of an object and its weight, could influence the pattern of response in ventral stream visual areas typically associated with perception of shape (lateral occipital cortex) and surface properties such as texture (posterior fusiform areas near the anterior portion of the colateral sulcus). The second experiment shows that weight-specific patterns of activity and patterns specific to the visual properties of stimuli can occur independently in the same area of cortex. These weight-specific patterns of activity were not found in early visual areas V1 and V2.

At first glance this new finding appears to challenge the two visual systems hypothesis since it demonstrates that information about the weight of objects that influences action (specifically the force applied to lift the object) is represented in the ventral stream - the purported seat of object identification. However, this finding is not at odds with a more nuanced reading of Milner and

Goodale's hypothesis. In contrast to the shape of an object and its position and orientation relative to our bodies, properties such as weight are not directly specified in the visual information available as we look at an object, but they are part of the object's identity. What does it mean to identify an object? Object identification is not simply object naming, it is recall of the constellation of properties and associations that distinguish *this* object from others. It is the process in which perception and memory become intertwined [4]. We might therefore view weight as being part of the identity of an object ('the heavy cylinder') rather than the directly specified spatial properties that determine, in a Gibsonian sense, how we may act upon it. Both types of information influence our actions [5]. Knowledge of the properties of objects beyond their geometry typically constrains the range of actions we apply to objects. We could grasp a mug so that its open end remains upwards or tilts sideways, but knowledge of the consequences if the mug is full affects the type of grasp we make.

Within the ventral stream there are distinct areas that respond to different properties of objects. Some of these areas seem to be specific to particular visual properties such as texture, colour or glossiness [6, 7, 8, 9] while others respond to multiple surface properties [10, 11]. One interpretation of these multiple representations is that areas responsive to combinations of surface properties are encoding more conceptual, as opposed to visual, properties of objects. In monkeys the more conceptual encoding occurs in more anterior areas [12] whereas more posterior areas respond to specific visual properties. Consistent with this, the area in the current study that responded both to visual properties and to expectations of weight coincides approximately with the areas of anterior collateral sulcus described by Cant, Goodale and their colleagues [10, 11] as opposed to the more posterior area identified by Cavina-Pratesi et al [6, 7].

We should not be surprised that information in the ventral stream can influence action. There are many ways in which the dorsal and ventral streams can interact [13]. The dorsal and ventral streams project to a number of common areas (e.g. TEO in the temporal lobe, prefrontal cortex). There are extensive cross-connections between dorsal and ventral streams. Feedback connections from either stream reach early visual areas that project to both streams. Independence between dorsal and ventral streams will generally only become apparent in normal observers (with intact brains) when responses are so speeded that there is not time for interaction through these pathways to occur. Neither the presence of these connections nor evidence such as that found by Gallivan and his colleagues invalidates Milner and Goodale's two visual systems hypothesis. Gallivan's findings, do, however, highlight the need to avoid overly simplistic interpretations of it.

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