Visual Cognition: Rats Compare Shapes Among the Crowd

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Abstract

Rats can discriminate simple shapes visually, even if they are moved around, made smaller, or
partially covered up; the strategy they use may help shed light on human brain mechanisms for
discriminating complex features, such as faces.

Look at any two people, places or objects, and you can almost immediately tell if they
appear the same or different from one another. Indeed, the remarkable speed with which we
can discern things based on their appearance suggests that our brains evolved specific
circuitries for realizing 'same *versus* different' by vision. Despite the significance of object
discrimination for day-to-day survival, the neural circuits and mechanisms that enable us to
distinguish even the most basic shapes still remain unclear. A new study reported in this
issue of *Current Biology* from Vermaercke and Op de Beeck [1] provides exciting new
insights into how the brain might distinguish visual shapes under both clear and uncertain
conditions.

Rodents as Emerging Models for Studying Visual Perception

What tools are available to probe the mechanisms underlying shape discrimination? Vision
has long been studied using psychophysics and neuronal activity recordings, mainly in
monkeys, cats and humans. That approach continues to provide insights into the structures,
cell types and receptive field properties in the visual pathway [2], and the neural correlates
of certain aspects of visual perception, such as directional motion [3]. In recent years,
however, new genetic tools have raised the opportunity not just to record from, but also to
label and control the activity of highly defined sets of neurons [4,5]. Because these genetic
tools are most easily applied to rodents, the field of visual neuroscience is now rapidly
expanding to include rats and mice as staple models for probing the circuits underlying
perception and decision-making [6].

There are obvious barriers to studying vision in rodents, not the least of which is that rodents
view the world at much lower resolution than do primates [6,7]. Nonetheless, recent
experiments have shown that rodent visual circuits bear many similarities to those of larger
species [6,8–10]. Indeed, many neurons in the primary visual cortex of mice (V1) have
receptive fields that are as highly tuned as those found in primate V1;mice just need to see
larger stimuli in order to activate those neurons [10]. Are the boundaries on studying visual
perception in rodents therefore simply a matter of scale? Or could it be that rodents are
fundamentally limited in terms of their ability to carry out complex 'higher order' tasks?
Moreover, given that the ultimate goal is to understand how humans make sense of the
visual world, it is crucial to determine not just if rodents can perform complex visual
discriminations, but the strategies they use.

A High-Throughput Paradigm for Probing Shape Recognition

In their paper in this issue, Vermaercke and Op de Beeck [1] report a paradigm for testing shape recognition in rodents. A water-deprived rat was placed into a chamber viewing two screens: one displaying a triangle, and the other displaying a square. In order to receive a water reward, the rat was required to touch a sensor near the screen displaying the square. Rats quickly learned this task, which is somewhat similar to tasks used in previous studies [11]. A key strength of this paradigm is that, because of their highly motivated state (the rats were thirsty) and the short time required to access reward (the chamber was small), the rats performed thousands of trials over a relatively short period of time. That provided a high-throughput, quantifiable platform for probing the strategies underlying shape discrimination.

'Bubbles' Reveal Where and How Rats Discern Shapes

Once they established that rats could perform the discrimination task, Vermaercke and Op de Beeck [1] explored which features of the visual stimuli the rats used to distinguish triangles from squares. Round masks called 'bubbles' were introduced to various portions of the visual stimuli such that, on any given trial, parts of both the square and triangle were occluded from view (Figure 1). After the experiment, the authors analyzed the statistics of the images that led to errors (trials when the rat went to the screen displaying the triangle) *versus* the statistics of the images that led to reward (trials when the rat went to the screen displaying the square). By 'reverse correlating' the image statistics with trial performance in this way, the authors were able to determine which portions of the visual stimuli were most relevant for shape discrimination.

Vermaercke and Op de Beeck [1] found that rats relied more heavily on the information in the lower portion of the display. As the authors aptly note, this strategy deviates from the 'ideal observer' scenario [12] — a psychophysical metric based on the theoretically optimal strategy of evaluating every pixel in the visual scene. Thus, rats use only a portion of the visual information available to them in order to discriminate shapes.

Rats Distinguish Shapes Irrespective of Position

One could imagine that rats do not really compare visual shapes *per se*, but rather that they adopt a simple strategy based on local differences in screen brightness, such as "the square is displayed on the screen that is brighter at the bottom". Vermaercke and Op de Beeck [1] tested this idea by analyzing the set of trials when bubbles occluded the lower parts of the image. Interestingly, the authors found that, when the lower field was covered, the rats adapted their strategy to compare the upper visual field instead. Thus, rats are not cemented to a fixed spatial regime for discriminating shapes. They may indeed have a simple, reflexive strategy that relies on lower field analysis, but as Vermaercke and Op de Beeck [1] show, rats can adopt new visual search and shape comparison strategies if that is what is required to satisfy their thirst.

Scale-Invariant Shape Discrimination

Can rats learn the difference between a square and a triangle even if those shapes are made smaller or moved to different locations within the display? In a second set of experiments (called 'Phase II'), the rats were tested for their ability to recognize shapes that were reduced to half of their initial size, and randomly placed within each display. As Vermaercke and Op de Beeck [1] point out, this required the rats to shift from a simple strategy of comparing matched locations in the two screens to a 'higher-order' strategy involving local comparisons of pixel content. In other words, the rats had to decide whether a given dark or light portion of the screen belonged to the shape or not. The rats' performance initially

dropped under these conditions but, with time, they learned to identify the triangle and the square nested among the bubbles, and discriminate them from one another. This is particularly intriguing because position and size invariance are visual challenges that humans confront every day as they search for physical objects in space.

Rats *versus* Humans

Another unique strength of the Vermaercke and Op de Beeck [1] study is that the authors directly compared rat *versus* human psychophysical performance. After adjusting the task to account for differences in spatial resolution, and so forth, human subjects were asked to distinguish squares and triangles masked behind bubbles. Some interesting differences quickly became apparent. First, humans never showed a bias towards particular portions of the display. Second, humans scanned and compared most of the visible area of the square and the triangle, indicating they act closer to the ideal observer model. Third, whereas none of the rats ever achieved >80% correct trials, humans achieved near perfect performance. The authors point out, however, that in a water-escape paradigm [13] rats too can exhibit near perfect discriminations, indicating that motivational state must be taken into account when comparing the performance thresholds of rodents and humans.

Implications for Understanding Visual Circuits

The new findings described by Vermaercke and Opde Beeck [1] extend on those from previous studies [11,13–16] by exploring complex aspects of shape discrimination, its context dependence, and the underlying strategies that rats follow. Their work also provides an important step forward toward the goal of linking specific cell types and circuits with higher order visual perceptions. One can now imagine combining the psychophysics paradigm described here with a head-fixed or mobile imaging protocol [16–18], to directly monitor and control [4,5] the activity of the brain circuits hypothesized to mediate shape recognition. These are truly exciting times for studying visual perception in rodents. As Vermaerke and Op de Beeck [1] rigorously show, rodents not only see, they can also perform discrimination tasks that parallel the visual challenges humans face every day. The general neural circuit mechanisms of shape perception are therefore within reach.

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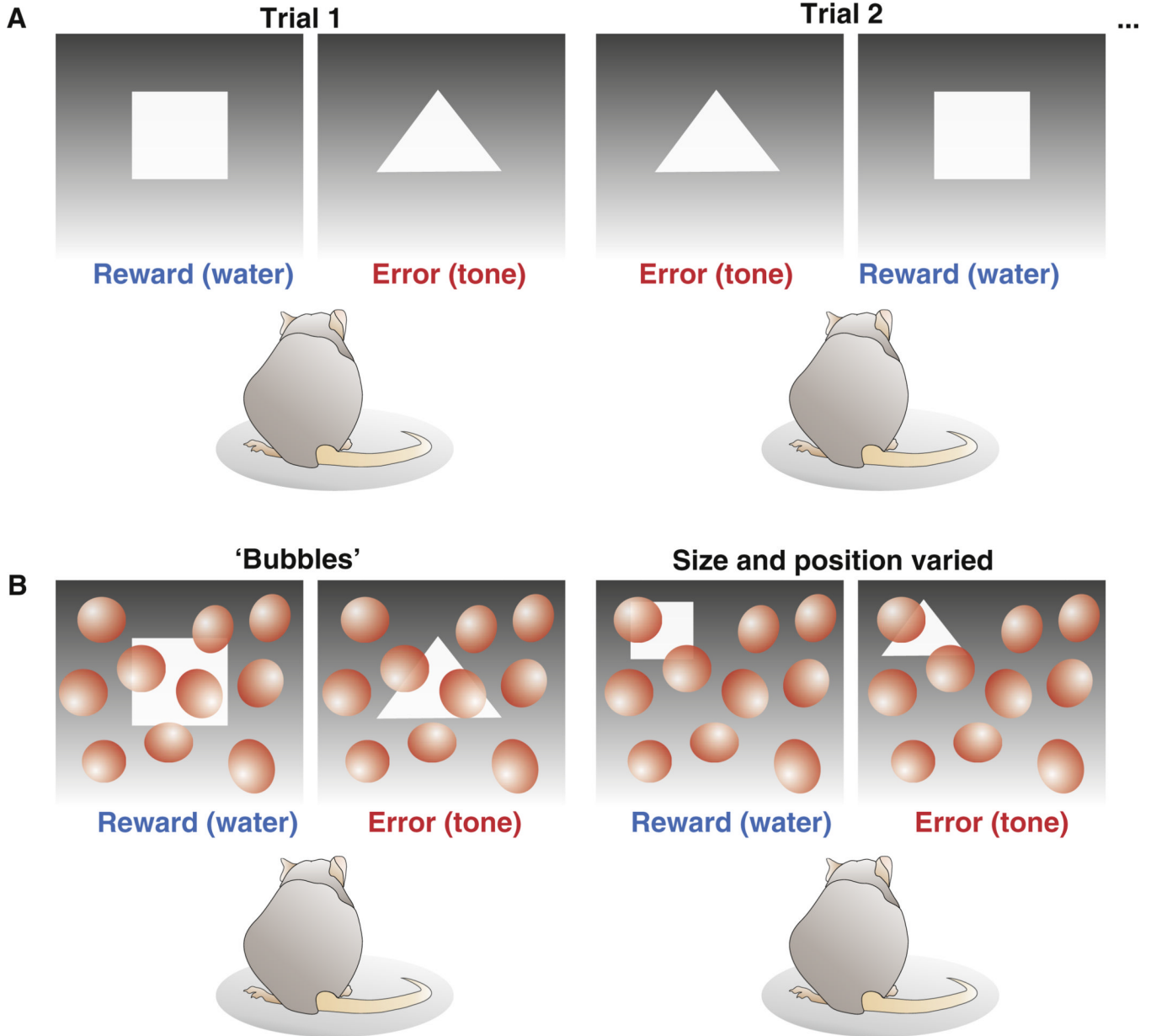
A

Trial 1

...

Trial 2

Reward (water)   **Error (tone)**   **Error (tone)**   **Reward (water)**

B

'Bubbles'

Size and position varied

Reward (water)   **Error (tone)**   **Reward (water)**   **Error (tone)**

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Figure 1. Shape recognition testing in rodents
(A) Top panels display the basic stimuli and experimental design whereby a rat has to visually discern a triangle from a square in order to receive a water reward. The reward source is coupled to the location of the screen displaying the square, which varies randomly from trial to trial. (B) Lower panels illustrate the 'bubbles' paradigm in which the test shapes are partially occluded and in some cases are also moved and/or made smaller. In the actual experiment, achromatic Gaussian blobs, rather than red balloons, were used as 'bubbles'. See [1] for details.