Non-accidental properties determine object exploration patterns

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Humans, in particular infants, tend to actively explore objects during familiarization. This exposes the visual system to a broad, and possibly structured, range of object views. If object learning and recognition is based on familiar views, how do we determine which views to rely on?

In computer vision, the implementational success of view- and appearance-based algorithms (e.g., ``bag of words'' methods) for object recognition has diminished the popularity of methods that focus on reconstructing three-dimensional structure. Unfortunately, this has resulted in the neglect of an interesting idea, on which view-invariant approaches were originally founded upon. That is, visual objects often present to the observer, ``non-accidental'' properties, such as symmetry, parallelism, etc., that are easily accessible across large variations in viewpoint. Here we investigate whether and how ``non-accidental'' properties influence the way in which we familiarize ourselves with novel objects for subsequent recognition.

In the present study, we created a large set of novel, three-dimensional objects with a random structure of protrusions and dents akin to lumps of clay (object type S0E0). These objects were subsequently modified to possess non-accidental properties: they were either stretched along one dimension to provide an axis of elongation (S0E1), or mirrored across the same dimension to introduce an axis of symmetry (S1E0), or both (S1E1). In our experiment, 22 participants were required to familiarize themselves with 4 novel objects by exploring them in 3D, such as to successfully discriminate between them. Four blocks of trials comprised the experiment. In each (randomized) block, participants first familiarized themselves with four labeled objects taken from one object type. These objects were presented individually and participants were able to actively explore them with a trackpad, which allowed for rotations about the horizontal and vertical object axes. After this, they were immediately tested on their familiarity with these four objects for which five objects were presented, including a novel distractor object. Participants were allowed to freely explore these objects and were required to label each object correctly. False responses were indicated with participants having to respond until the correct response was achieved. The whole learning and test phase was repeated if any mistake was made. Each block of trials ended only when participants achieved the test criterion of correctly identifying all objects. Apart from measuring the number of repetitions to reach criterion, we also analyzed the object rotations participants made during object exploration.

Our analysis of the behavioral performance indicated that symmetrical objects were easier to learn and recognize than asymmetrical objects with test criterion reached with fewer responses on symmetrical objects ($F_{1,21}=10.7$, $p<0.05$). Performance was not significantly better on elongated objects compared to non-elongated objects ($F_{1,21}=0.3$, $p=0.59$). Interestingly, there were distinctive object exploration patterns for the separate object types: exploration for S0E0 objects tended to be random, whereas exploration for S1E0 objects was constrained to views that fell along the symmetry axis. For S0E1 objects, exploration was focused on two views on the ends of the elongation axis, as well as around the elongation axis. Finally, exploration of S1E1 objects yielded a combination of the two single strategies with a preference for views along the symmetry axis as well as those on the ends of the elongation axis. The exploration pattern was the same for both learning and test trials, although exploration time in the test trials was much shorter overall.

Our results suggest that ``non-accidental'' properties play an important role during object processing in two ways. First, the presence of symmetry reduces the time required for effective object familiarization. Second, elongation and symmetry appear to constrain object exploration during learning and recognition. Participants gravitated towards views that were well-defined in terms of their spatial relationship to the principal axes of elongation and symmetry, in accordance to their availability. This study indicates that the way we access characteristic object views for object recognition during learning and recognition is influenced by ``non-accidental'' properties of an object's structure. It is likely that computer vision algorithms for object recognition could be rendered more effective by constraining view-selection by ``non-accidental'' properties, as is reflected by the current observations of human object exploration.

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