Spontaneous discrimination of possible and impossible objects by newly hatched chicks

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Four-month-old infants can integrate local cues provided by two-dimensional pictures and interpret global inconsistencies in structural information to discriminate between possible and impossible objects. This leaves unanswered the issue of the relative contribution of maturation of biologically predisposed mechanisms and of experience with real objects, to the development of this capability. Here we show that, after exposure to objects in which junctions providing cues to global structure were occluded, day-old chicks selectively approach the two-dimensional image that depicted the possible rather than the impossible version of a three-dimensional object, after restoration of the junctions. Even more impressively, completely naive newly hatched chicks showed spontaneous preferences towards approaching two-dimensional depictions of structurally possible rather than impossible objects. These findings suggest that the vertebrate brain can be biologically predisposed towards approaching a two-dimensional image representing a view of a structurally possible three-dimensional object.

Keywords: impossible objects; early predispositions; object perception; domestic chick

1. INTRODUCTION

The human visual system seems to be equipped with mechanisms to establish whether or not a two-dimensional image represents a view of a structurally possible three-dimensional object. An example is provided by the so-called impossible objects, first described by Penrose & Penrose [1]. These consist of two-dimensional figures at first perceived as representing a projection of a three-dimensional object, but then immediately and effortlessly recognized as an object that cannot actually exist in the form interpreted by the visual system.

Several local cues need to be integrated to detect global inconsistencies in structural information, allowing discrimination between possible and impossible objects; a long-standing debate exists as to the role played by experience with real three-dimensional objects in the development of these abilities [2,3].

Recently, Shuwaieri et al. [4] reported that four-month-old infants can discriminate between structurally possible and impossible objects. However, four months leaves plenty of time for visual experience with objects, and the issue of the relative contribution of maturation of biologically predisposed mechanisms and experience with real objects remains unsolved.

Animal models allow for controlled-rearing experiments that would be impossible with human newborns. In particular, the hatchlings of precocial species (such as the domestic fowl) show adult motor behaviour soon after birth, making it possible to combine adequate control of specific experiences and behavioural testing in a newborn animal [5]. Domestic chicks display at birth, well-documented predispositions towards preferentially detecting and approaching selected object features [6–8]. Early predispositions are likely to have been evolutionarily shaped in order to maximize the chances that the animal is exposed to, and therefore imprints onto, adequate objects (which typically are possible three-dimensional objects in a natural environment). Further considerations make the domestic chick a suitable model system for the purpose of our study. This species has been shown to possess perceptual mechanisms that are implicated in the evaluation of a two-dimensional image as a view of a structurally possible three-dimensional object. Chicks successfully recognize objects (geometric shapes such as triangles or squares) even when they are partly occluded [9,10]. They also react to objects according to their relative distance, as defined by pictorial cues such as occlusion [11,12].

Here, we aimed to check whether discrimination of structurally possible from impossible three-dimensional objects may be possible soon after birth, and to assess the role of past experience with real objects in the emergence of this ability. Our hypothesis is that newly hatched chicks shall be precociously capable of detecting, and would preferentially approach, a three dimensionally possible object as compared with a three dimensionally impossible object. If this is the case, it provides novel evidence concerning the developmental (and possibly innate) nature of coherent shape processing.

2. MATERIAL AND METHODS

(a) Subjects

Subjects were 157 female domestic chicks (Gallus gallus) either purchased from a commercial hatchery when they were a few hours old (n = 91), or coming from eggs incubated and hatched in controlled laboratory conditions (n = 66). Controlled hatching was required for testing naive chicks. The fertilized eggs were purchased at the 14th day of incubation and were kept in an incubator (MG70/100 Rurale). On day 17, eggs were placed into a hatchery (MG100), where they were maintained in total darkness, until hatching on day 21.

(b) Stimuli

Stimuli were static two-dimensional images, printed on a 6 × 6 cm white plastic paper, representing solid edges constituting a 3.5 cm size solid that might or might not be perceived as a three-dimensional cube, depending on the overlapping of intersections between edges that in three-dimensional cubes should lie in different perspective planes.

(iii) Rearing stimulus

The stimulus used for familiarization provided no information concerning the critical intersections, these being occluded (figure 1a) by black drawing pins (diameter 1 cm). Owing to the process of amodal completion, human adults see these stimuli as three-dimensional cubes.
(ii) Testing stimuli
All chicks at testing were faced with the choice between a possible and an impossible version of the non-occluded cube. In the possible version (figure 1b), interposition cues of the edges in the critical points were coherent, so that the edges that should be in the first plane were not interrupted by edges underneath. To a human observer, edges appear as correctly overlapping and the stimulus is perceived as a structurally coherent two-dimensional representation of a three-dimensional cube. In the impossible version of the cube (figure 1c), the interposition cues caused the edges lying on the second plane to interrupt those on the first plane. The perceptual result to the human observer was an incoherent two-dimensional representation of a three-dimensional solid cube.

(c) Rearing conditions
All chicks obtained from the commercial hatchery were familiarized with the rearing stimulus (i.e., the occluded version of the cube) over 3 days post-hatching before the test. During this time, they were housed singly in standard metal cages (28 cm width × 40 cm depth × 32 cm height) at controlled temperature (28°C–31°C) and humidity (68%), with food and water available ad libitum. A subgroup had experience of physical occlusion of objects and of environmental features (occlusion condition, n = 42) during the 3 days of rearing. This was provided by printing the rearing stimulus onto both sides of two identical vertical screens (8 cm × 14 cm) that were placed within the rearing cage, at the corners. The food jar was positioned behind one screen and the water jar behind the other screen, so that birds learned to associate food and water with the stimulus. Each screen (together with its food/water jar) was moved to a different corner within the cage twice a day, to prevent positional learning. The remaining chicks that had become familiar with the rearing stimulus did not experience any sort of physical occlusion of one object onto another (no occlusion condition, n = 49) as such stimuli were printed onto little (6 × 6 cm) rigid flags highly visible on top of the food or water jars. The two flagpoles (diameter 0.1 cm) holding each flag were bound directly on the edge of the glass jars, so that the base of stimuli was just over the rim of the jar. Jar positions, at the corners of the cage, were changed randomly within the cage twice a day.

A separate group of chicks came from dark-incubated and dark-hatched eggs (naive condition, n = 66). They underwent a spontaneous preference test between possible and impossible figures at 24 h post-hatching, during which time they were kept in a thoroughly dark environment, and therefore lacked any visual experience prior to the test.

(d) Test apparatus and procedure
The experimental room, located near the rearing room, was kept at controlled temperature (25°C) and humidity (70%); the only light came from a lamp (40 W), placed 25 cm above the apparatus. The apparatus consisted of a cage identical to the rearing ones, with the floor and internal walls lined with uniform white plastic sheets. On one of the short walls were hung the two testing stimuli, spaced 10 cm apart, at 3 cm from the floor and 5 cm from the side walls (figure 1d). The left/right position of the stimuli was balanced across individuals.

At the beginning of the test, each chick was positioned at the starting point, i.e., at the exact midline of the short wall (about 3 cm away from it) opposite to where the stimuli were, so that it faced them. Each chick was then observed for 6 consecutive minutes, during which time it could freely move within the apparatus and approach either stimulus.

The internal area of the apparatus was virtually divided into three areas: two identical and symmetrical choice areas situated by each stimulus (14 cm width × 25 cm depth) and a no-choice area located away from the stimuli, by the opposite wall (28 cm width × 15 cm depth), which contained the starting point. Choice of the possible (or impossible) figure was scored, using a computerized event recorder: every time the bird entered (with its head and at least half its body) a certain choice area, the time (s) counter for that area was set until the chick had walked out of it. The overall number of seconds spent by the chick within the choice area located by the two stimuli during the whole test was considered.

Since we expected a preference for the perceptually coherent stimulus, an index of choice of the possible cube was computed.
logical motion patterns rather than other kinds of exhibit a spontaneous preference to approach biological motion [14]. Here the fact that visually inexperienced chicks spontaneously preferred to approach the possible cube suggests that at birth, chicks not only possess mechanisms to establish pictorial depth perception (§1) but that they use them to integrate image fragments into spatially coherent three-dimensional object representations. Stimuli that cannot be successfully processed as globally coherent three-dimensional objects may be regarded as less attractive by chicks.

It may be argued that evidence from precocial species cannot easily be transferred to altricial (slowly developing) species, and in particular to the most altricial of the species, the human one. Nonetheless, from a computational point of view, these results show that, in principle, natural selection can produce organisms perfectly able to deal with the problem of global coherence in three-dimensional objects as recovered from two-dimensional images in the absence of any specific experience of real three-dimensional objects. This has obvious implications with regards to the current debate (e.g. [3]) about the role of innateness and learning on the origins of knowledge.

The experiments comply with the current Italian (Ministero della Sanità, Dipartimento Alimenti, Nutrizione e Sanità Pubblica Veterinaria – Ufficio X) and European Community laws for the ethical treatment of animals.

Figure 2. Choice (group means ± s.e.m.) displayed at test by chicks in the three rearing conditions, expressed as preference for the possible cube. The horizontal dashed line represents chance level (y = 50%). The asterisk represents p > 0.05, one-sample two-tailed t-tests.

according to the formula: (time by the possible cube/total time spent by either stimulus) × 100. Values at around 50 per cent indicated no preference; values greater than 50 per cent indicated a preference for the possible cube and those less than 50 per cent indicated a preference for the impossible cube.

3. RESULTS

Results are shown in figure 2. A one-sample two-tailed t-test was performed to compare chicks’ responses with chance level (50%), separately for the three experimental conditions: occlusion: mean = 63.48; s.e.m. = 4.45; t41 = 2.86, p = 0.006; no occlusion: mean = 57.99; s.e.m. = 3.08; t48 = 2.58, p = 0.013; naive: mean = 58.01; s.e.m. = 2.06; t65 = 3.89, p = 0.0001.

In all conditions, chicks significantly preferred to approach the ‘possible’ cube.

An analysis of variance considering the three experimental conditions as between factors did not reveal any effect owing to different rearing (F2,154 = 0.95; p = 0.39).

4. DISCUSSION

Newly hatched chicks are able to discriminate between two-dimensional images depicting possible and impossible three-dimensional objects. Chicks selectively approached the possible cube, which they probably regarded as more similar to the partly occluded object experienced during familiarization. The lack of difference between the first two experimental conditions strongly suggests that experience of occluding events is not necessary for the emergence of such discrimination. Even more convincing, visually naive chicks, tested soon after hatching as they emerged from an incubator in which they had been kept in darkness, showed a spontaneous preference for the possible version of the cube.

It is known that, as a result of exposure to a particular object in early life, nidifugous birds develop a social and exclusive attachment to a particular object, a process dubbed ‘filial imprinting’ [13]. It is also known that some stimuli are more effective than others in eliciting imprinting. For example, naive chicks at their first exposure to point-light animation sequences exhibit a spontaneous preference to approach biological motion patterns rather than other kinds of motion [14]. Here the fact that visually inexperienced chicks spontaneously preferred to approach the possible cube suggests that at birth, chicks not only possess mechanisms to establish pictorial depth perception (§1) but that they use them to integrate image fragments into spatially coherent three-dimensional object representations. Stimuli that cannot be successfully processed as globally coherent three-dimensional objects may be regarded as less attractive by chicks.

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