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Young chicks rely on symmetry/asymmetry in perceptual grouping to discriminate sets of elements

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Grouping sets of elements into smaller, equal-sized, subsets constitutes a perceptual strategy employed by humans and other animals to enhance cognitive performance. Here, we show that day-old chicks can solve extremely complex numerical discriminations (Exp.1), and that their performance can be enhanced by the presence of symmetrical/asymmetrical colour grouping (Exp.2 versus Exp.3). Newborn chicks were habituated for 1 h to even numerosities (sets of elements presented on a screen) and then tested for their spontaneous choice among what for humans would be considered a prime and a non-prime odd numerosity. Chicks discriminated and preferred the prime over the composite set of elements irrespective of its relative magnitude (i.e. 7 versus 9 and 11 versus 9). We discuss this result in terms of novelty preference. By employing a more complex contrast (i.e. 13 versus 15), we investigated the limits of such a mechanism and showed that induced grouping positively affects chicks' performance. Our results suggest the existence of a spontaneous mechanism that enables chicks to create symmetrical (i.e. same-sized) subgroups of sets of elements. Chicks preferentially inspected numerosities for which same-sized grouping is never possible (i.e. the prime numerosity) rather than numerosities allowing for symmetrical grouping (i.e. composite).

1. Introduction

Humans can capitalize on non-symbolic perceptual mechanisms (e.g. grouping) to solve a symbolic task (e.g. enumeration) [1,2]. We are faster at enumerating a set of elements when these are divided into same-sized subsets (symmetrical grouping). When elements are not presented as grouped, we can actively implement the grouping strategy, although performance worsens with larger sets. Moreover, independently of the set numerosity, we are slower in enumerating prime numbers, an effect that has been ascribed to the impossibility of grouping a prime numerosity into same-sized subsets (asymmetrical grouping) [1]. Disassembling a numerosity into same-size subsets (symmetrical grouping) can constitute a non-mathematical strategy allowing subjects to discern prime and non-prime numerosities [3]. Here, we investigate whether day-old domestic chicks could capitalize on such a symmetrical grouping strategy to discriminate between two sets of elements, one that does not allow division into equal-sized subsets (i.e. a prime number) and one that does allow for symmetrical grouping.

Birds display non-symbolic numerical abilities akin to humans and can also exploit analogous cognitive and perceptual strategies, suggesting similarities in the underlying mechanisms [4–6]. In particular, young chicks allow early testing of visually guided behaviours, and soon after hatching they were shown to process object symmetry [7,8], rely on Gestalt principles [9], respond to spatial and numerical information [10] and benefit from induced grouping strategies [11].
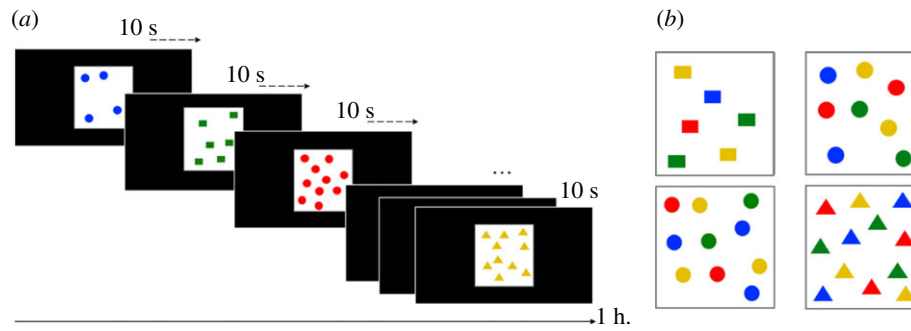
Figure 1. (*a*). The habituation procedure (with examples of the stimuli used in Exp.1 and Exp.2). Each chick was individually exposed for 1 h to a sequence of stimuli depicting an even number of elements. Each stimulus appeared in the centre of the screen and after 10 s it was replaced by a subsequent stimulus. In all experiments, the sequence of the different stimuli was randomly determined. The position of the elements within each stimulus was pseudo-randomly determined so that two elements could never overlap. In Exps. 1 and 2, the elements within each stimulus were of the same colour and shape. In Exp.3, elements within each stimulus were of four different colours (see (*b*)). (*b*) Examples of the multi-coloured stimuli used for habituation in Exp.3. In Exp.3, elements within the same stimulus had the same shape, whereas the colour of the elements was pseudo-randomly determined so that two elements located in close proximity from one another were never of the same colour. (Online version in colour.)

To test our hypothesis, we tested newly hatched chicks (after a brief habituation, see §2(b)) in a spontaneous choice task between two sets of elements, one of which could never be grouped symmetrically (i.e. being a prime numerosity). In Exp.1, chicks were tested with either 7 versus 9 or 9 versus 11, aiming at assessing a possible role of numerical magnitude (i.e. the prime numerosity was either the larger or the smaller in the comparison). Additionally, by employing a more complex discrimination (i.e. 13 versus 15), we explored processing limits in the capability to discriminate (Exp.2) and whether passively induced grouping (i.e. elements presented as already chunked by colour, Exp.3) could help chicks overcome such limits. We employed sets of large numerosities each having a high ratio value. This is the fraction between the larger and the smaller set in the comparison, and it is considered an index of the difficulty in discriminating between two numerosities: as the ratio value approximates 1 discrimination becomes harder, as it approximates 0 difficulty decreases. Numerical cognition studies usually employ comparisons between much smaller quantities, e.g. 1 versus 2, 1 versus 3 or 2 versus 3 [12,13] or, with a much smaller ratio between the two sets, e.g. 5 versus 10 [13], 10 versus 20 or 20 versus 40 [14]. Comparisons such as 7 versus 9 or 9 versus 11 involve both large numerosities and a high ratio (0.78 and 0.82, respectively). It is unlikely that chicks could rely on numerical information to solve the task. Such complex comparisons were indeed aimed to trigger the use of a non-numerical strategy, favouring the emergence of a perceptual mechanism.

2. Material and methods

(a) Subjects

We tested a total of 158 domestic chickens (*Gallus gallus*). Fertilized eggs were provided by a local hatchery (Incubatoio La Pellegrina, San Pietro in Gu, PD, Italy) and were incubated in the laboratory (Comparative Cognition Lab, Dept. of General Psychology, University of Padova) at controlled temperature (37.5°C) and humidity (55–66%) in a FIEM incubator MG 70/100 (cm 45 × 58 × 43). Soon after hatching, each chick underwent a 2 h experimental procedure.

(b) Habituation

The apparatus consisted in two white plastic walls arranged to form a triangular arena (93 cm base × 62 cm length × 30 cm

height), with the longer side being a monitor (Samsung FHD, 24′, 60 Hz) onto which the stimuli were projected. The vertex opposite to the monitor constituted the subject's starting point (i.e. where the chick was gently placed at the beginning of the habituation). Habituation took place individually for each chick.

During habituation chicks were presented for 60 min with a random sequence of stimuli, each depicting an even number of elements (figure 1a). Every stimulus appeared in the centre of the screen and remained visible for 10 s, and then it was immediately replaced by the subsequent stimulus. Thus, each chick saw in total a random combination of 360 stimuli. For each stimulus, the colour (i.e. red, blue, yellow or green) and shape (i.e. triangles, rectangles or circles) of its elements, as well as of the numerosity, always even, of the set (i.e. 4, 6, 10 or 12 elements) was randomly determined. All elements comprised in a stimulus were positioned within a white squared area (336 px) in the centre of the screen; the spatial location of each element was pseudo-randomly determined so that elements never overlapped with one another. Each element covered a total area of 36 px.

In Exps.1 and 2, all the elements in a same stimulus were of the same colour and shape. In Exp.3, elements within one stimulus had all the same shape, but they were of different colours so that all four colours available were presented within each stimulus. To avoid familiarizing the subjects with any sort of colour chunking during habituation, the elements located in close proximity were never of the same colour (figure 1b). In addition, before running the experiment, we had asked four independent and expert human scorers to inspect a large subgroup of the stimuli checking for pop out grouping. Each scorer inspected on average 360 habituation stimuli, as in a whole habituation session. The human eye is as sensitive as the chicks' eye to Gestalt principles [9]. If any of the stimuli were considered as biased (i.e. could potentially lead to a grouping effect), these were immediately discarded from the set and substituted by new stimuli that were also controlled for possible pop out grouping.

The habituation phase lasted 1 h, during which the chick could freely move and approach the screen. The test took place 1 further hour after the end of habituation.

(c) Test

For Exp.1, day-old domestic chicks ($n = 79$, 40♀) were asked to discriminate sets of either: 7 versus 9 ($n = 40$, 19♀) or 9 versus 11 ($n = 39$, 21♀) elements. In Exp.2 ($n = 39$, 27♀) and Exp.3 ($n = 40$, 19♀), chicks were tested in the discrimination of 13 versus 15 elements. A new group of chicks participated in each experiment (and each experimental condition, in the case of Exp.1), so that each individual chick was only tested once.
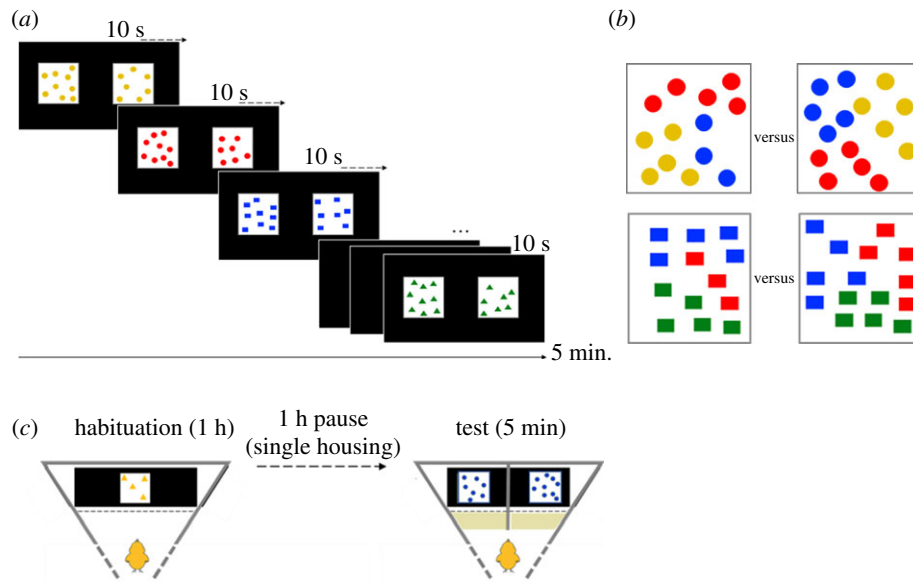
Figure 2. (*a*). The test procedure (in the example, the 7 versus 9 condition of Exp.1, with the prime numerosity presented on the right side). At test, two stimuli were projected at once, one in the right and the other in the left half of the screen. Throughout the test, the left–right position of the two numerosities remained identical for each subject (their position was randomized across subjects). During the 5 min of the test, new pairs of stimuli were presented on the screen every 10 s. The two stimuli simultaneously presented were always of the same colour (except for Exp.3, see (*b*)), and their elements were of the same shape. As for the habituation, the spatial arrangement of the elements in each stimulus was pseudo-randomly determined, and the presentation order of the stimuli followed a random sequence. (*b*) An example of the testing stimuli used in Exp.3 (13 versus 15, in this example, the prime number is on the left side). Perceptual grouping was passively induced in Exp.3 by presenting the elements as already chunked by colour into three subsets (same-coloured elements were always close to each other). In the stimulus depicting the prime numerosity (13), the three subgroups were made of five, five and three elements; in the stimulus depicting the non-prime odd numerosity (15), each of the three subgroups comprised five elements. (*c*) Experimental procedure. During habituation (left) each chick saw for 1 h a customized combination of multiple sets of even numerosity, each being individually presented on the screen for 10 s. At test (right), chicks were presented with pairs of stimuli comparing two odd numerosities (one prime and one composite). (Online version in colour.)

For all experiments, the test arena was the same employed during habituation. But at test, the screen was divided into two separate halves by a vertical plastic partition (5 cm base × 30 cm height). This made it possible to present two test stimuli at once on the screen (i.e. either in the left and right half of it). The test consisted of a 5 min presentation of pairs of novel stimuli (figure 2*a*). The two sets simultaneously displayed were identical for the shape and colour of the elements but differed in their numerosity. In Exp.1, one stimulus was a prime number, either 7 or 11, and was confronted with a stimulus depicting the composite numerosity 9 (symmetrical). In Exps.2 and 3, a set of 13 elements (asymmetrical—prime) was confronted with a set made of 15 elements (symmetrical—composite). In all experiments, for the same chick, the prime numerosity was presented in the same position (either left or right) throughout the test. The position of the prime numerosity was counterbalanced between subjects, to avoid any possible influence on the overall results of a side bias.

As for the habituation, random combinations of stimuli were presented throughout the test (a new pair of stimuli every 10 s). Overall, during the test, each chick saw 30 pairs of sets. The shape and colour of the elements were randomly determined and varied from pair to pair for the same chick. Sets simultaneously visible were always made of elements of the same colour and same shape (using the same set of colours and shapes of the habituation) but depicted two numerosities never experienced by the chick before. Both numerosities at the test were in fact odd numerosities (in that, both differed from the habituation stimuli); however, only one of them allowed for symmetrical grouping (i.e. odd composite, as for the habituation stimuli).

In Exps.1 and 2, all of the elements of the two stimuli simultaneously presented were of the same colour, whereas in Exp.3, each stimulus comprised elements of three different colours. In this case, same-colour elements were always adjacent to prompt grouping of the set into three subsets (i.e. 5 + 5 + 5 for

the non-prime odd and 5 + 5 + 3 for the prime numerosity) (figure 2*b*).

We scored the time each chick spent in either choice area (the shaded area in front of each stimulus) and considered it as a preference for the corresponding stimulus.

3. Results

In Exp.1 (figure 3*a*), chicks were randomly assigned to the 7 versus 9 ($n = 40$) or to the 9 versus 11 ($n = 39$) comparison. We found an effect of number (GLMM analysis of deviance, $X^2 = 6.49$; $p = 0.011$): chicks spent longer by the prime (i.e. 7 or 11) rather than the composite (i.e. 9) numerosity in both comparisons (i.e. their preference was independent of numerical magnitude) (*post hoc* analysis, estimate = −30.8; s.e. = 11.8; $t = −2.616$; $p = 0.0098$). We did not find any effect of the condition (i.e. 7 versus 9 or 9 versus 11), neither when we considered the solely condition ($X^2 = 0.797$; $p = 0.372$) nor its interaction with the stimulus ($X^2 = 0.234$; $p = 0.629$). Therefore, we assumed that the two conditions were not different in difficulty for the chicks (the average choice time was the same) and that the preference would not change between them (being there no stimulus*condition interaction). The first approach was at chance (prob = 0.557; s.e. = 0.0561; $z = 1.004$; $p = 0.351$). In Exp.2 (figure 3*b*), we aimed to investigate whether chicks' performance was affected by set size and tested them with 13 versus 15 ($n = 39$). In this case, no significant difference emerged in the time spent near either stimulus (*post hoc* analysis, estimate = 31.6; s.e. = 22.4; $t = 1.412$; $p = 0.162$) nor in the first set approached (*post hoc* analysis, prob = 0.475; s.e. = 0.079; $z = −0.316$; $p = 0.752$). In Exp.3 (figure 3*b*), grouping was passively induced as test elements were chunked by
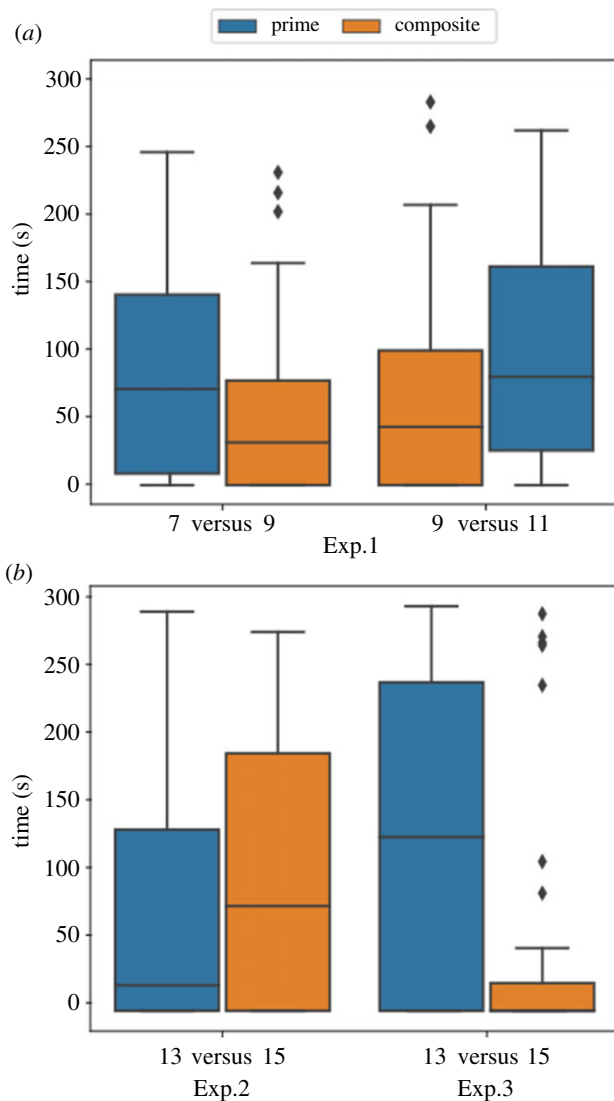
Figure 3. Time (s) spent at test closer to the prime (blue) or to the composite (orange) numerosity. (a). Exp.1: chicks preferred the prime numerosity (7 or 11) irrespective of numerical magnitude. (b) 13 versus 15 comparison: in Exp.2, no preference for either stimulus emerged; in Exp.3 (with induced grouping), chicks preferred the set grouped asymmetrically. Diamonds represent outliers (i.e. any values over 1.5 times the interquartile range over the 75th percentile or any values under 1.5 times the interquartile range under the 25th percentile). Please note that the increased presence of outliers in Exp.3, especially for the time spent near 15, is a by-product of the median being 0, as in this case the interquartile range becomes very small. Regardless, we did not apply any criterion of removal of outliers from the analysis: all subjects are included in the statistical models to avoid overestimating the effect. (Online version in colour.)

colour into three smaller subgroups: 5 + 5 + 5 (symmetrical, for 15) and 5 + 5 + 3 (for 13) (figure 1b) ($n = 40$). In this case, we found a preference for the prime numerosity both in the first approach (*post hoc* analysis, prob = 0.706; s.e. = 0.078; $z = 2.326$; $p = 0.02$) and in the time spent by each stimulus, which was higher for 13 over 15 (*post hoc* analysis, estimate = −83.5; s.e. = 22.5; $t = −3.707$; $p > 0.001$).

4. Discussion

In the first experiment, chicks spent longer close to the set of 7 or 11 elements rather than that of 9 elements. Number-based strategies unlikely account for these results because the comparisons employed involved large numerosities and were characterized by a high ratio (see introduction). Moreover, numerical strategies cannot explain the direction of preference (choice of prime irrespective of it being larger or smaller in the comparison). Avoidance of numerosity 9 is also implausible, as it has never been reported in this species, and in a previous study, chicks did choose 9 in the 6 versus 9 comparison [13]. We hypothesized that discrimination relied on purely perceptual mechanisms such as disassembling the sets and comparing the resulting subgroups. Direction of the choice indeed may have resulted from chicks' preference for novelty and/or asymmetry, a well-known phenomenon in this species [7,15]. Prior to test, chicks were habituated to even numerosities, which are more similar to non-prime odd numerosities. Both even and non-prime odd numerosities allow for symmetrical grouping. For instance, 6 can be symmetrically grouped as 3 + 3 or 2 + 2 + 2; similarly, the odd non-prime number 9 can be disassembled in 3 + 3 + 3, also symmetrical. On the contrary, a prime number can only be grouped asymmetrically, i.e. at least one of the subsets comprises a different numerosity. The familiar test environment and the familiar appearance of stimuli for colour and shape likely prompted a preference for slight novelty (asymmetrical grouping) [15,16]. Early predispositions for visual asymmetry might have also played a role. These were reported for newly hatched [7] and week-old [8] chicks and bear significant ecological value.

In the second experiment, we tested chicks in the 13 versus 15 comparison. In human subjects, sets' numerosity affects performance: we are slower at enumerating a set as its numerosity increases [1,2]. We reported a similar effect in chicks, as they failed to discriminate between the two sets and chose randomly. We hypothesized a limit linked to working memory constraints in the number of subgroups (up to 3–4) and/or their size (up to 3–4 elements in each subgroup). Previous studies on numerical discrimination indicated a maximum limit of four 'files' simultaneously represented in working memory [11]. Passively induced grouping (e.g. presenting the elements as already chunked) can help overcome this limit, enhancing performance in chicks [11] and infants [17]. If chicks relied on a symmetry-based perceptual mechanism, induced grouping should facilitate discrimination. Results from Exp.3 confirmed this hypothesis, showing that chicks could solve the discrimination, and that preference for the asymmetrical set (i.e. 13) was restored. The emergence of a preference already in the first approach might constitute further evidence of induced grouping facilitating discrimination.

In all the experiments, chicks were exposed to even numerosities (i.e. that allow for symmetrical grouping) and eventually tested with two odd numerosities, only one of which did allow for symmetrical grouping. Chicks showed a preference for the numerosity that could never be disassembled into same-sized subsets (i.e. asymmetrical). To discriminate they might have relied on a perceptual strategy, disassembling each set into smaller (and possibly same-sized) subgroups. The prime numerosity would be perceived as novel, due to its perceptual asymmetry (i.e. at least one subgroup must be of a different numerosity). Chicks are known to preferentially explore slight novelty of the stimulus after habituation [15,16] and to display a spontaneous preference for asymmetric patterns [7,8]. A combination of both could also be at the basis of chicks' choice.

The colour grouping presented in Exp.3 may have stressed the imbalanced pattern of the elements (symmetry versus asymmetry hypothesis). By contrast, it may have created a higher visual complexity: in the case of the prime, chicks were exposed to two numerosities (13 = 5 + 5 + 3), whereas in the case of the composite number chicks saw only one numerosity being repeated (15 = 5 + 5 + 5). In this case, chicks might have been attracted by the co-occurrence of novelty (i.e. asymmetrical pattern) but also higher overall complexity of the configuration. This redundancy of information might have played a role in helping chicks to overcome their spontaneous limit in discriminating these two sets. It would be important to devote more studies to better disentangle the different role of visual complexity and perceptual asymmetry. However, while in Exp.3, grouping was prompted by colours of the items, In Exp.1 no perceptual cue for prompting grouping was provided, therefore the chicks had to spontaneously disassemble the sets into (if possible, symmetrical) subgroups. Under this condition, both sets could be disassembled asymmetrically as non-prime numbers can also be asymmetrically grouped. Notably, however, chicks preferred the prime (i.e. 7 or 11) to the composite (i.e. 9) numerosity, supporting the idea of a perceptual mechanism that prioritizes symmetrical configurations. It seems that this mechanism is spontaneously available and prioritizes symmetrical configurations (thus allowing identifying those numerosities that always result in asymmetrical subgroups, i.e. prime). It remains to be clarified whether, by imposing an asymmetrical pattern (e.g. by presenting elements as colour grouped), it would be possible to prompt a response to also non-prime asymmetrically grouped numerosities.

Overall, our data show that day-old chicks could solve a very complex discrimination between two sets of large numerosities with a high ratio (Exp.1). When the discrimination becomes too difficult (Exp.2), the performance can be restored by a passively induced cognitive strategy (i.e. colour grouping, Exp.3). Young chicks seem to represent and mentally manipulate sets of elements by disassembling them into smaller subgroups. As reported for both adult humans [1] and children [2], this strategy implies symmetrical grouping and benefits from passively induced grouping [1,17]. These results provide the first experimental evidence of a spontaneous non-mathematical mechanism based on symmetry detection in an animal model. This result is in line with clinical evidence from individuals with a diagnosis of savant syndrome, who could recognize and/ or generate prime numbers in the absence of mathematical skills [3,18]. Data from a non-mammalian species are particularly insightful as they imply an analogous and widespread mechanism in vertebrates, opening an investigation into its neurological basis. Since our subjects were day-old chicks, at least in this species mechanisms involved must be available very early during development and do not require formal training.

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