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COMPARATIVE AND ONTOGENIC PHYSIOLOGY

The Notions of Size and Shape in Old World Monkeys (*Macaca mullata*): A Comparative Analysis of the Formation Process

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Abstract—In everyday life, humans and animals occupying different rungs of the "evolutionary ladder" often have to evaluate the notions of larger/smaller size (predator/prey, rival/ally, etc.) and flat/volumetric shape (fruit/leaf, 2D/3D images, etc.). The aim of this study was to find out experimentally which of the following two tasks related to the formation of the preverbal notions of larger/smaller size or flat/volumetric shape is easier to train rhesus monkeys. The first task was to form or actualize the notion of larger or smaller size upon co-presentation of 4 flat or volumetric figures. The second task was to form or actualize the notion of flat or volumetric object among 4 figures of the same size (small, medium or large) presented simultaneously. To be rewarded during the formation of both notions, the animal was supposed to choose a figure which was different from the other three in the trial. In both tasks, the number of trials required to reach or exceed the 70% level of correct task implementation per each type of training was counted. This allowed optimization of the notion formation algorithm to rule out strong skill consolidation (overtraining) that might inhibit the formation of a new skill in further training. When the number of trials was averaged over all types of training, the notion of shape formed faster than the notion of size. This discrepancy was only observed under the difficulty of solving one of the task types—discriminating between objects poorly distinguishable (1.5 times) by their size. However, in the situation of no difficulty in discriminating between figures during their perception (more than a 2-fold difference in size), the number of trials in forming the notions of size and shape was statistically indistinguishable. Since training rates in forming the notions of larger/smaller size or flat/volumetric shape were indistinguishable in simple choice situations, we suggest that these notions are equally important for rhesus monkeys.

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Key words: abstract thinking, notion of size, notion of shape, skill, rhesus monkeys.

INTRODUCTION

Despite long-lasting endevour, the problem of studying thinking and intelligence in animals and humans remains at the core of contemporary cognitive science. There are lots of definitions of thinking and intelligence [1–3]. In our understanding, thinking is a multicomponent cognitive function responsible for making decisions by means of the trial-and-error method and/or intelligence in the process of implementation of various tasks. Intelligence, which consists of inductive reasoning (proper reason), deductive reasoning (judgement capacity) and mind [4], is incorporated into the concept of thinking and represents a top of its "pyramid". In the present work, we only consider inductive reasoning responsible for the synthesis of discrete empirical concepts (visual images) which leads to the formation of empirical concepts (notions), namely, relative preverbal notions of larger/smaller size and flat/volumetric shape.

In the relevant literature, there are numerous experimental studies on the formation of the concept of reasoning due to synthesis of notions as various symbols and objects in anthropoids [5–10] and monkeys [11–16]. Using flat and/or volumetric figures as stimuli, it was shown that Old World and New World monkeys can form the notions of larger or smaller by size [11, 12, 17] as well as by quantity [18–22]. However, there are no works that would carry out a detailed comparative analysis of the number of trials needed to form the notions of size and shape although this would be extremely important for adequate interpretation of the training outcome.

The aim of the present study was to find out experimentally which of the two tasks concerned with the formation of the notion of size and the notion of shape is easier to train rhesus monkeys. For this purpose, there was conducted a comparison between the number of trials needed to reach the 70% level of correct task implementation when forming the notion of size (larger/smaller) and the number of trials when forming the notion of shape (flat/volumetric).

It is important to point out that the more consolidated the skill (situation of overtraining) the more difficult it is to form a new reflex or a new notion. This statement illustrates the experiment reported in the literature [23]. Rhesus monkeys were trained to choose a larger of the two black triangles drawn against the white background. Quite a lot of trials (305) proved to be needed to reach the 80% level criterion of correct answers over the last 3 experimental days by 20 trials per each. A change of the background (the same black triangles now against the green background) served a signal to choose, instead, a smaller triangle of the two presented simultaneously. This switchover from the notion of larger to the notion of smaller required 1.5 times more trials (460) as compared to the number of trials in forming the notion of a larger of the two.

When forming notions, our task was to optimize the training algorithm in such a way that it would rule out strong skill consolidation able to inhibit the formations of the next skill. On the one hand, it was necessary for the monkey to solve the task properly but, on the other hand, it was equally important to preclude the transformation of task implementation into an instrumental reflex. Based on this reasoning, we took as a training criterion a single attainment or excess of the 70% level of correct task implementation.

MATERIALS AND METHODS

Animals and maintenance conditions. Experiments were carried out on three adult females of the rhesus monkey *Macaca mullata* aged 16–17 years and weighing 5–7 kg. All three training enclosures were in the same room where a 12 h/12 h day/night (light on/light off) lighting regime was constantly maintained. Enclosures were disposed in such a way that animals could establish visual contacts with each other. Monkeys were fed with natural produces according to a daily ration approved at the Sechenov Institute. Monkeys' weight was regularly monitored. All experiments were carried out in compliance with the Sechenov Institute's protocol of handling laboratory animals based on the European Union Directive 86/609/EEC on the protection of animals used for experimental and other scientific purposes.

Experimental setup. The setup was assembled from the following units.

1. Experimental table equipped with two screens made, respectively, from transparent and opaque plexiglass that could be alternately raised and dropped using special fixers.

2. Box-like apparatus, sized 500 × 200 × 200 mm, standing on the experimental table with 4 platforms on the upper horizontal plane to attach figures. The frontal vertical plane carried 4 inbuilt drawer-like feeders, each corresponding to a definite platform. Correct choice by pressing the figure on the platform 1 ensured access to the feeder 1 with a reward. In another trial, correct pressing the figure on the platform 2 led to draw out the feeder 2, and so on. Incorrect choice of a figure led to block all feeders.

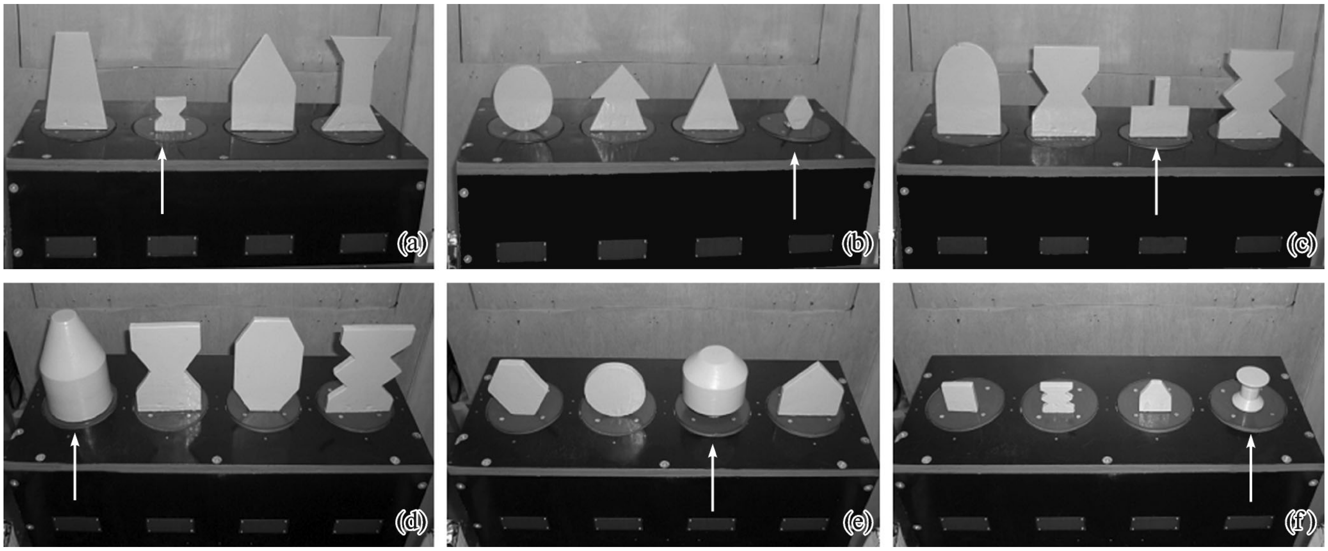

Fig. 1. Examples of geometrical figures in trials to form the notions of larger/smaller size (here, of smaller size between flat figures—(a), (b), (c)) and flat/volumetric shape (here, volumetric shape— (d), (e), (f)). (a) Choice of a small figure among the three large; (b) choice of a small figure between the three medium; (c) choice of a medium figure between the three large; (d) choice of a large volumetric figure between the three large flat; (e) choice of a medium volumetric figure between the three medium flat; (f) choice of a small volumetric figure between three small flat. *Arrow* indicates correct figure choice.

3. Automatic feeder control unit to operate its opening upon correct choosing a figure and blockage upon incorrect choice.

4. Plywood screen (10 mm thick) to visually isolate the monkey from the experimenter who could thus observe animal behavior on the computer monitor. This piece of equipment was intended to prevent any involuntary tips from the experimenter during the trial. All manipulations on removing 4 figures of the previous trial from the platform and installing 4 figures for a new trial were executed while both screens, transparent and opaque, were raised.

5. PC with web camera for online video monitoring of animal behavior during the experiment. Video records were then stored in PC for subsequent versatile analysis upon the cessation of the experiment.

Geometrical figures of choice. Flat (8 mm thick, equal to 10% of the maximum width) and volumetric wooden figures of diverse configurations and the same light green color differed in their size—large (120 mm high), medium (80 mm high) and small (40 mm high)—and were attached upright to the platforms. Thus, large figures differed from small ones 3 times, medium from small—2 times, and large from medium—1.5 times. The number of figures was large enough for the figures to be repeated as rarely as possible during the experiment (by 15–16 figures of each type making up totally 93 figures). The distance from the monkey cage to the figure attachment on four platforms was 23 cm. The level of monkey's eyes during task implementation was predominantly 20 cm above the horizontal surface of the apparatus with 4 platforms. Angular dimensions for the small, medium and large figures were 9, 17 and 25°, respectively. Monkeys were trained to form the following notions: 2 notions of size (larger vs. smaller) and 2 notions of shape (flat vs. volumetric).

Trial description. The monkey went over on her own from the home to the wheeled experimental cage which was then moved with the animal inside to a separate experimental room. Each trial (definite combination of 4 figures presented simultaneously) began from letting the opaque screen down: in this situation the monkey could see the figures on the apparatus but could not reach them. Then, in 10 s, the transparent screen was let down and the animal could choose any of the 4 figures by means of pressing it. It is necessary to point out that all 4 feeders remained loaded throughout the experiment for the animal to be unable to make its choice being guided by the presence of absence of the food smell in one of the feeders. If the monkey chose the right figure, it was automatically food rewarded in this trial (the feeder moved out). Boiled potatoes or Nesquik dry breakfasts were used as a trial reward. If the animal erred, all feeders were automatically blocked and the monkey received no reward in this trial. In each trial, figures on 4 platforms were arranged in a pseudorandom order to prevent reflex formation to a definite figure and/or platform. Figure 1 exemplifies geometrical figures as presented in trials to form the notions of larger/smaller size (a, b, c) and the notions of flat/volumetric shape (d, e, f).

Forming the notions of larger/smaller size. The choice of a single figure from the 4 possible was investigated. In each trial, only two sizes of figures were presented. When forming (actualizing) the notion of size (larger vs. smaller), there were used either 4 flat figures or 4 volumetric figures co-presented to the animal in the trial. The following 6 size combinations were possible:

1. 1 large figure + 3 small figures;
2. 1 small + 3 large figures;
3. 1 medium + 3 small figures;
4. 1 small + 3 medium figures;
5. 1 large + 3 medium figures;
6. 1 medium + 3 large figures.

During this training, the choice of a larger figure in odd trials and that of a smaller figure in even trials were considered correct answers. Figure combinations 1 and 2 allowed discrimination between large and small figures (the large/small training type); figure combinations 3 and 4 provided the medium/small training type while those 5 and 6—the large/medium training type. In forming the notion of size, there were involved 12 training types (6 upon presentation of flat and 6—of volumetric figures).

Forming the notions of flat/volumetric shape. When forming (actualizing) the notion of shape (flat vs. volumetric), 4 figures of the same size were co-presented to the animal in the trial. The following shape combinations were used in training:

1. 1 small volumetric + 3 small flat figures;
2. 1 small flat + 3 small volumetric figures;
3. 1 medium volumetric + 3 medium flat figures;
4. 1 medium flat + 3 medium volumetric figures;
5. 1 large volumetric + 3 large flat figures;
6. 1 large flat + 3 large volumetric figures.

During this training, the choice of a volumetric figure in odd trials and that of a flat figure in even trials were considered correct answers. Shape combinations 1 and 2 provided discrimination between small flat and small volumetric figures (the small flat/volumetric training type); shape combinations 3 and 4 provided the medium flat/volumetric training type, and those 5 and 6—the large flat/volumetric training type. In forming the notion of shape, there were involved 12 training types on two monkeys.

Within a single experimental day, each monkey was presented with no more than 21 trials which included 2–3 training types in forming the notions either of size or shape. The training process was alternate: the first notion of size (e.g., larger) was formed first and then, beginning from the next day, there was formed the first notion of shape (e.g., volumetric). Training of each pair took 7–10 days. 3–4 weeks later, the second notion of size (e.g., smaller) was formed and then, beginning from the next day, there was formed the second notion of shape (e.g., flat), and so on. The rest interval was introduced to partially extinguish already formed skills resulting from previous raining.

A training criterion in forming (actualizing) notions. We trained rhesus monkeys at a daily basis until a single attainment or excess of the 70% level of correct task implementation over 1 experimental day. Each experimental day, the number of trials with correct and wrong answers was counted, and trials were only summated on those days when the level of correct answers did not reach the 70% level criterion. On the experimental day, when the criterion was attained or exceeded, the number of trials carried out during this day was disregarded. Thus, if, for example, the animal reached the 70% level criterion of task implementation as soon as the first experimental day, then, according to our preselected algorithm, the number of trials required to attain this criterion was 0 showing that the criterion was attained virtually at once (during a single experimental day).

The 70% level of correct task implementation was chosen not at random. On the one hand, it was necessary that the monkey could solved the task properly, but, on the other hand, it was also important that task implementing would not turn into an instrumental reflex, i.e. the monkey would

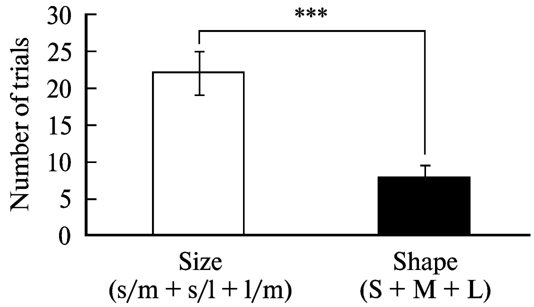

Fig. 2. A comparison of averaged values over all training types in forming the notion of size with those in forming the notion of shape. *Ordinate*: the number of trials (mean ± SE) needed for a single attainment or excess of the 70% level criterion of correct task implementation. *Abscissa*: (s/m + s/l + l/m) —averaged values of the number of trials in forming the notion of size (smaller vs. larger) using the following figures: small/medium (s/m), small/large (s/l) and large/medium (l/m); (S + M + L)—averaged values of the number of trials in forming the notion of shape (flat vs. volumetric) among the small (S), medium (M) and large (L) figures. Data presented for two monkeys. *Asterisks* indicate statistically significant differences (***—$p < 0.001$) obtained using the paired *t*-test.

not be overtrained, because this hampers the formation of the next notion [23].

Statistical data treatment. We used the Graph Pad Instat statistical software package. It was established that all data samples were tested for normality, and hence the one-way ANOVA and the paired *t*-test were used for data treatment.

RESULTS

One of the three rhesus monkeys failed to be trained any notions. This monkey was abandoned by her mother at infancy and raised separately from her own family group. Having matured, she was characterized by a high basal anxiety level (frequent stereotyped going round the home cage). Transportation to another room during the experiment caused an extremely negative emotional response which inhibited all kinds of training. Two other monkeys were quite successful in implementing all tasks posed.

A comparison of averaged values for all three trial types needed to reach or exceed the 70% level criterion in forming the notion of size (22 ± 3) vs. the notion of shape (8 ± 2) yielded a high significance level ($p < 0.001$; Fig. 2). Figure 2 shows that rhesus monkeys form the notion of shape (a choice between flat and volumetric figures) much faster than the notion of size (a choice between larger and smaller figures). Then we decided to scrutinize these data and ascertain the reason behind such a preference for one of the two abovementioned key characteristics of the object when solving visual tasks in rhesus monkeys.

Figure 3a presents data on the number of trials needed to reach or exceed the 70% level of task implementation in forming the notion of size with the involvement of the following training types: small/large, small/medium and large/medium. Figure 3a shows that monkeys need significantly greater number of trials to reach the requisite criterion with the involvement of large and medium figures (l/m; 42 ± 8) than with that of small and large figures (s/l; 12 ± 2, $p < 0.001$) as well as small and medium figures (s/m; 12 ± 3, $p < 0.001$). Figure 3b demonstrates that the training rate in forming the notion of shape (flat/volumetric) is approximately equal in all three training types irrespective of the figure size: small (S; 8 ± 2), medium (M; 9 ± 3) or large (L; 7 ± 1).

Since the number of trials needed to reach or exceed the 70% level of task implementation in forming the notion of size with the involvement of small and large figures (small/large) as well as small and medium figures (small/medium) was statistically indistinguishable (Fig. 3a), we averaged the data over all these training types. Then we compared this averaged result (s/m + s/l; 12 ± 2) with the number of trials with the involvement of large and medium figures (l/m) in forming the notion of size as well as with the average number of all trial types in forming the notion of shape (S + M + L). The outcome of this comparison using the one-way ANOVA is shown in Fig. 3b. The number of trials needed to reach the 70% level in forming the notion of size with the involvement of large and medium figures (l/m) differed statistically both from the average number of trials with the involvement of small/medium and small/large figures (s/m + s/l) with $p < 0.001$ and the average number of trials in forming the notion of shape (S + M + L) with $p < 0.001$. However, the average number of trails in forming the notion of size with the involvement of small/large and small/medium figures (s/m + s/l) was statistically indistinguishable from the average number of trials in formin the notion of shape (S + M + L; Fig. 3c).

DISCUSSION

Our results indicate that on average 12 trials were needed to exceed the 70% level of correct answers with the involvement of small/large and small/medium figures whereas 42 trials were required to reach the same criterion with the involvement of large/medium figures in forming the notion of size (larger vs. smaller). When forming the notion of shape (flat vs. volumetric), about 8 trials were needed to reach our preselected training criterion. In the study by V.S. Nikitin and L.A. Firsov [23], rhesus monkey required quite a large number of trials (305) to reach the 80% level criterion of correct answers during 3 last experimental days, by 20 trials per day. Even considering that 5 years before the onset of these experiments monkeys were actively involved in the study on discriminating one figure from the two when forming the notions of shape, size and quantity, it is safe to say that our training algorithm implying no strong skill consolidation (a method of a single attainment of the 70% level of task implementation) significantly reduced the number of trials to 12–42 in rhesus monkeys when training the notion of size by choosing one figure out of four. Despite the aim of our study was more complicated than the above-mentioned work, we nevertheless managed to obtain such a considerable reduction in the number of trials when attaining the training criterion due to the reselected training algorithm. Analogous data on decreasing the number of trials from 305 to 110 in training the notion of larger upon co-presentation of two images and using the criterion of a single attainment of the 90–100% level of correct answers were also obtained in rhesus and capuchin monkeys [11].

A comparison of averaged values of the number of trials over all training types in forming the notion of size with those in forming the notion of shape leads to the following outcome: the notion of shape forms significantly faster than the notion of size (Fig. 2). However, a detailed analysis of the number of trials needed to reach the 70% level criterion in forming the notions of size and shape (Fig. 3c) shows that the rate of forming the notions

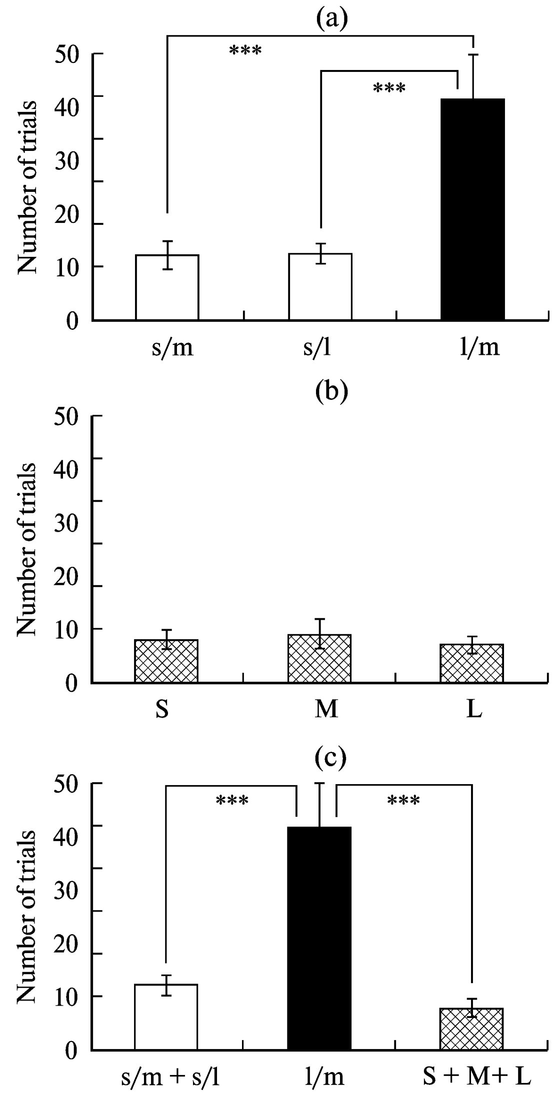

Fig. 3. A comparison of the number of trials needed for a single attainment or excess of the 70% level criterion of correct task implementation. *Ordinate*: the number of trials (mean ± SE); (a) comparison of the number of trials in forming the notion of size (smaller vs. larger figure) in the following training types: small/medium (s/m), small/large (s/l) and large/medium (l/m). One-way ANOVA: $p = 0.0002$, $F_{2.33} = 10.927$; (b) comparison of the number of trials in forming the notion of shape (flat vs. volumetric) in discriminating between the small (S), medium (M) and large (L) figures. One-way ANOVA: $p = 0.1797$, $F_{2.25} = 1.840$; (c) comparison between averaged values of the number of trials in forming the notion of size using small/medium and small/large figures (s/m + s/l), large/medium figures (l/m), and averaged values of the number of trials in forming the notion of shape using small, medium and large figures (S + M + L). One-way ANOVA: $p < 0.0001$, $F_{2.33} = 13.107$. *Asterisks* indicate statistically significant differences (***—$p < 0.001$) obtained using a Tukey–Kramer post hoc test for multiple comparisons.

of size and shape are statistically indistinguishable in the situation when there are no difficulty in discriminating between figures because small (height 4 cm, angular size 25°) and medium (height 8 cm, angular size 17°) figures differed 2 times by size and 1.9 times by visual angle while the difference between small and large (height 12 cm, angular size 25°) figures was 3 times by size and 2.8 times by visual angle. Since training rates in forming the notions of larger/smaller size and flat/volumetric shape did not differ from each other in simple choice situations, it is possible to assume that these notions are equally important of rhesus monkeys. At the same time, significant differences in the rate of forming both notions (a comparison of the number of trials with the involvement of large and medium figures in forming the notion of size and the number of trials in forming the notion of shape as seen in Fig. 3c) may arise due to difficulties in discriminating objects when medium (height 8 cm, angular size 17°) and large (height 12 cm, angular size 25°) figures differ by size and visual angle only 1.5 times.

CONCLUSION

We propose herein a training algorithm which optimizes the number of trials needed to reach a definite criterion when forming notions in monkeys. The meaning of the algorithm consists in the absence of strong skill consolidation which inhibits the formation of the next skill. In averaging the values over all trial types, the notion of shape formed significantly faster than the notion of size. However, as a result of detailed analysis, it was found out that the number of trials in forming the notions of size and shape was statistically indistinguishable in the situation of no difficulty in discriminating between figures at their perception (more than a 2-fold difference in size), whereas the differences in the number of trials in forming these two notions appear when there is a difficulty in discriminating between object sizes (less than a 1.5-fold difference in size).

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