

A Comparative Analysis of Global and Local Processing of Hierarchical Visual Stimuli in Young Children (*Homo sapiens*) and Monkeys (*Cebus apella*)

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Results obtained with preschool children (*Homo sapiens*) were compared with results previously obtained from capuchin monkeys (*Cebus apella*) in matching-to-sample tasks featuring hierarchical visual stimuli. In Experiment 1, monkeys, in contrast with children, showed an advantage in matching the stimuli on the basis of their local features. These results were replicated in a 2nd experiment in which control trials enabled the authors to rule out that children used spurious cues to solve the matching task. In a 3rd experiment featuring conditions in which the density of the stimuli was manipulated, monkeys' accuracy in the processing of the global shape of the stimuli was negatively affected by the separation of the local elements, whereas children's performance was robust across testing conditions. Children's response latencies revealed a global precedence in the 2nd and 3rd experiments. These results show differences in the processing of hierarchical stimuli by humans and monkeys that emerge early during childhood.

In a now classic article, Navon (1977) proposed that a global precedence in the processing of hierarchical stimuli, such as a number of small geometric shapes spatially arranged to form a larger geometric shape, has a general adaptive value (e.g., in allowing economy of processing resources). The generality of this global advantage should pertain particularly to the primate order, because all primates are highly reliant on vision and no obvious differences have been reported in the primary and secondary visual pathways of different primate species, including humans (De Valois & De Valois, 1988; Fagot & Deruelle, 1997; Fobes & King, 1982). Nevertheless, comparative analyses of response times and percentages of correct responses in a number of paradigms featuring the presentation of hierarchical stimuli point to interspecies differences between human adults, who typically process the global shape of the stimuli faster and at a higher level of accuracy, and monkeys, which show the opposite pattern of results by processing faster and more accurately the local features of the stimuli (Fagot & Deruelle, 1997; Hopkins & Washburn, 2002). Chimpanzees, in contrast with monkeys, do not seem to show either a global or a local advantage in their response accuracy and do not always process faster the local features of the stimuli (Fagot & Tomonaga, 1999; Hopkins & Washburn, 2002).

Interspecies differences emerging between adult humans and nonhuman primates are of interest because they challenge the notion of the universality among primates of a global advantage in the processing of hierarchical stimuli (Fagot & Deruelle, 1997). For this reason it is important to assess the conditions under which different organisms show a facilitation, if any, in the processing of one level of visual stimuli over the other and the adaptive value that this bias might have for different organisms. In fact, considering the similarity of the visual system of human and nonhuman primates (De Valois & De Valois, 1988; Fobes & King, 1982), interspecies differences are likely to be related to higher visual functions rather than to peripheral sensory ones.

Given that in other cognitive domains it has been shown that cognitive differences between human and nonhuman primates are not always clear cut when young children are compared with adult monkeys (e.g., Chalmers & McGonigle, 1984; De Lillo & McGonigle, 1997; Frigaszy, Galloway, Johnson-Pynn, & Brakke, 2002; Johnson-Pynn & Frigaszy, 2001), it is important to provide information concerning when, during development, the differences in the mode of processing of hierarchical stimuli start to emerge.

In early development studies, there was a consensus that the development of perceptual skills progresses along a local-to-global trajectory. Some researchers reported that infants younger than 3 months of age attend mainly to the constituent parts of a visual stimulus (Carey & Diamond, 1977; Elkind, Kogler, & Go, 1964), whereas the ability to integrate individual elements of a pattern into a coherent whole develops several months later (Cohen, 1998). Conversely, other empirical evidence suggests that newborns and young infants are more sensitive to the configurational properties of stimuli than to their component elements (Ghim & Eimas, 1988; Kemler, 1983; Quinn, Burk, & Rush, 1993; Slater,

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Mattock, Brown, & Bremner, 1991; Vurpillot, 1976). More recent data indicate that such a global advantage can be affected by the manipulation of the spatial frequency (Macchi Cassia, Simion, Milani, & Umiltà, 2002) and the familiarity with the stimuli (Colombo, Freeseaman, Coldren, & Frick, 1995).

Also, studies with preschool children have yielded contradictory results concerning young children, who have been regarded on some occasions as mainly global processors and on others as being better able to process the local features of complex visual stimuli (see Dukette & Stiles, 2001, for a review). Moreover, preschool children seem to be more easily affected by manipulations of the stimuli, such as the relative density of the local elements, than older children and human adults. For example, using a forced choice procedure resembling a matching-to-sample (MTS) task, Dukette and Stiles (1996) reported that 4-year-olds showed a local bias when the experimenters reduced the density of the stimuli by eliminating some local elements of hierarchical stimuli, whereas in the same conditions 6-year-olds and adults maintained a global bias. Overall, studies focusing on preschool children seem to be underrepresented in the developmental literature compared with studies that have investigated infants, schoolchildren, and adult humans.

Moreover, considering that different developmental studies are not based on the same tasks and procedures and that, often, the use of different methodologies has yielded different results with young children, inferences concerning interspecies differences between young children and nonhuman primates are difficult to draw on the basis of published literature. In addition to these difficulties, developmental studies in this research area have often required verbal or pictorial descriptions of the stimuli (Dukette & Stiles, 2001; Prather & Bacon, 1986), making the tasks unsuitable for comparative analyses.

The aim of this study is to collect data on preschool children that warrant meaningful comparisons with data recently collected on tufted capuchin monkeys (Spinozzi, De Lillo, & Truppa, 2003) on an MTS task featuring hierarchical visual stimuli. Therefore, we tested children using stimuli, apparatus, and procedures that were as similar as possible to those used with monkeys by Spinozzi et al. (2003). Our experimental manipulations included the presentation of consistent stimuli (hierarchical patterns in which the shape of the local elements was the same as the global shape of the stimulus) and inconsistent stimuli (hierarchical patterns in which the shape of the local elements was different from the shape at the global level). Stimulus consistency is a variable that traditionally has been used in adult human studies to show that the interference produced by the presentation of inconsistent stimuli can selectively affect the processing of the local (but not the global) shape of the stimuli (Navon, 1977). Moreover, considering the potentially important role of stimulus density in affecting the ability of the participants to integrate local elements in a global whole (Martin, 1979), this variable was manipulated in another experiment to evaluate whether it played a selective role in the processing of hierarchical stimuli by children and monkeys.

Because the use of children as experimental subjects required (to prevent boredom) a reduction of the overall number of trials and conditions used with monkeys, subsets of trials derived from the experiments carried out on monkeys were administered to preschool children. Comparative analyses were then carried out, in which only trials that both species had received were included.

Experiment 1

Experiment 1 aims to detect possible differences in the mode of processing of hierarchical forms by young children and adult capuchin monkeys. Because the existing literature we have reviewed indicates that development has an impact on part-whole integration and that children show a weaker bias than adults toward the global processing of hierarchical stimuli, we predicted that differences between children and capuchin monkeys would still emerge but would be smaller than those observed in studies that have compared other nonhuman primate species with adult humans (e.g., Fagot & Deruelle, 1997).

As experiments conducted on hierarchical stimuli in humans typically use response times as a measure that is indicative of the priority given to the processing of a particular level of hierarchical stimuli (see Navon, 1977), we included a response time analysis of the data collected on children as an additional direct measure of the relative speed of processing and as an indirect measure of the cognitive demand imposed by the different conditions featured in our study.

Method

Subjects

The human (*Homo sapiens*) subjects were preschool children aged between 35 and 55 months from a local nursery in Leicester, England. Initially, 13 children were chosen to participate, on the basis of their willingness to be tested and their parents' consent; however, 2 children were excluded from the study for failure to reach the criterion of three consecutive correct responses in an MTS training phase (see *Procedure* section) after the presentation of 16 trials. Out of the remaining 11 children, 4 were male and 7 were female, with a mean age of 45.27 months ($SD = 5.97$). To our knowledge, none of the children had previous experience with similar experimental tasks. Their nursery activities did not involve tasks or games resembling MTS procedures.

Data for the monkey sample were obtained from the 3 adult tufted capuchins (*Cebus apella*; a male, Gal, aged 10 years and 10 months; a male, Pepe, aged 14 years and 5 months; and a female, Pippi, aged 19 years and 5 months) tested in the study by Spinozzi et al. (2003), to which the reader can refer for further details. The monkeys received an extensive identity MTS training prior to testing and had to satisfy a criterion of 90% correct before entering the experiment proper.

Stimuli and Apparatus

The hierarchical stimuli used in the present study are presented in Figure 1. They were identical to those used by Spinozzi et al. (2003) with capuchin monkeys and consisted of large (4 cm) circles (C) and squares (S) made up of 12 smaller (0.5 cm) circles (c) and squares (s), henceforth labeled as Cc, Cs, Ss, Sc, with the capital letter indicating the global shape and the small letter indicating the local shape.

The apparatus used with children in all the phases of the present study (see Figure 2) consisted of a vertical wooden panel (length = 46.0 cm, width = 35.0 cm, depth = 0.5 cm). It was mounted on a wooden base shaped into a house with two symmetrical square openings (5.0 cm \times 5.0 cm) situated 21.0 cm from the bottom of the panel and 15.0 cm apart from each other and covered with wooden slides (length = 7.0 cm, width = 13.0 cm, depth = 0.2 cm). These wooden slides could be moved sideways to cover or uncover the openings. The two comparison stimuli were placed on these two wooden slides. Between the two openings, there was an enclosed square into which the sample stimulus could be placed. The apparatus was

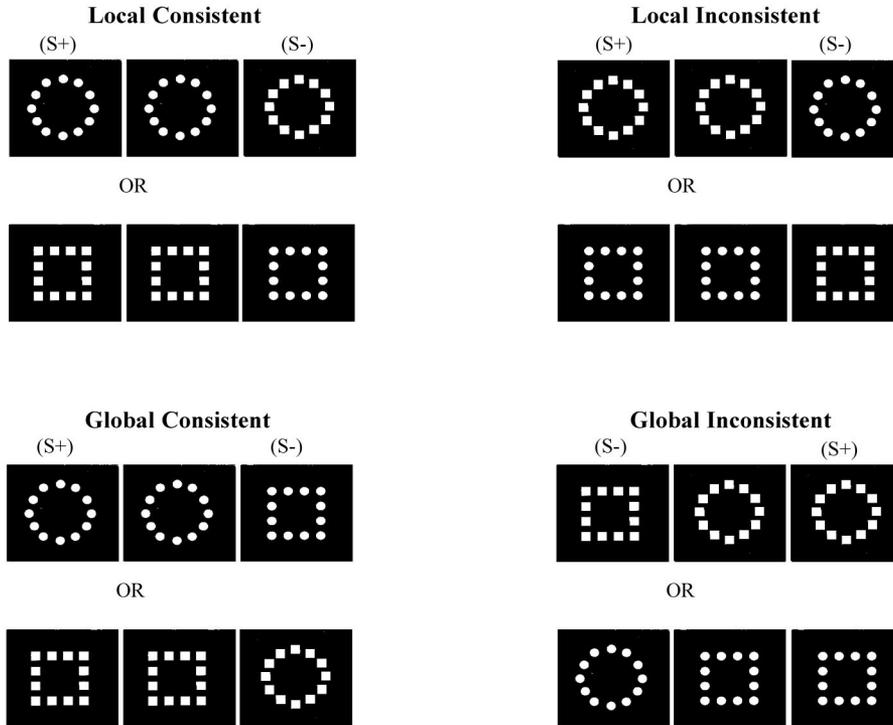


Figure 1. Stimuli used in the different conditions of Experiment 1. S+ = matching stimulus; S- = nonmatching stimulus.

placed on a table. A small toy teddy bear was used as an object that the children had to find and was placed at the back of the matching stimulus (S+). In between the trials, a black cardboard screen was placed between the child and the apparatus.

The apparatus used for the monkeys by Spinozzi et al. (2003) and from which the apparatus used in this study was derived was similar to the apparatus we have described, with the exception that some parts were made of polyvinyl chloride and that it was mounted on a trolley.

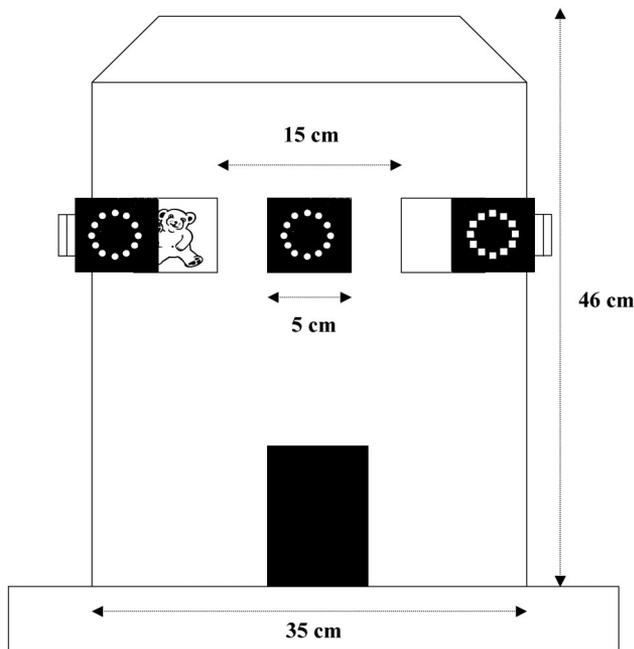


Figure 2. The apparatus used with children.

Procedure

The experiment was based on an MTS task. Each child was tested individually and was seated directly in front of the apparatus, which was described to the child as “teddy’s house.” Two experimenters administered the test. The first experimenter explained to the child that teddy liked to play the game hide and seek and that he would like to play the game with the child. The experimenter informed the child that teddy always hides behind the “window” (the square openings covered by the comparison stimuli) that looks “most like” the middle “window” (the sample stimulus).¹

While the first experimenter was giving these instructions to the child, the second experimenter covered the apparatus with the black screen and then placed the sample stimulus between the two square openings and placed the comparison stimuli, the matching stimulus (S+) and the non-matching stimulus (S-), into the slides covering the square openings. Finally, the second experimenter placed the teddy behind S+ and lifted the screen. The first experimenter then asked the child to point to the “window” behind which he or she thought the teddy was hiding. Children were

¹ The use of verbal instructions instead of the presentation of a lengthy pretraining phase was motivated by previous experience (De Lillo & McGonigle, 1997) showing that children of this age group become easily tired during Wisconsin General Testing Apparatus testing. As such, the use of a lengthy pretraining phase, requiring the children to discover the task requirements by themselves through trial and error, was not a viable option.

not explicitly instructed to respond as quickly as possible. However, it is possible that they noticed that their responses were timed by one of the experimenters. The child's response was recorded on a check sheet, as was the time taken to make the response, measured with a stopwatch. Each time the child made a correct response, he or she was rewarded with a small star sticker. If the child made an incorrect response, he or she was not rewarded but instead was reminded of the rules and encouraged to try again.

We took several precautions to avoid providing the child with spurious cues concerning the location of the toy teddy bear. Not only was the hiding procedure performed behind the black screen, out of the view of the participant, but also one experimenter interacted with the child and diverted his or her attention while the other experimenter prepared a new trial. Moreover, the base of the teddy bear was covered with cloth to minimize the possibility of auditory cues being provided when the toy was placed into the correct position on the apparatus. One of the experimenters sat slightly behind the child and in a lateral position. As such, the child could only observe her face by turning his or her head. The other experimenter was almost entirely occluded by the apparatus. Both experimenters were extremely careful in avoiding giving spurious cues by means of their body posture or the direction of their gaze during the trials.

MTS training. Following the procedure adopted by Spinozzi et al. (2003), before the test with hierarchical stimuli, the children were trained on a general MTS task with four noncompound stimuli to ensure that they understood the MTS procedure. The stimuli measured 3.0 cm × 3.0 cm and were printed as white shapes on a black background. The training continued until a criterion of three correct responses on three successive trials was achieved. The left–right position of S+ and S– followed a pseudorandom presentation whereby S+ could not appear on the same side in more than two consecutive trials.

Global–local test. Immediately after the child had reached the training criterion, he or she was tested on the global–local processing of the hierarchical stimuli. During the testing session, each child participated in two different matching conditions. In the global matching condition, S+ was identical to the sample, and S– differed from the sample only at its global level. In the local matching condition, S+ was identical to the sample, but S– differed from the sample only by its local elements. Each participant performed one session of 32 trials that comprised 16 global trials and 16 local trials, pseudorandomly interspersed so that trials belonging to the same condition could not appear more than twice consecutively. During the session, each stimulus was presented eight times as the sample. Each comparison stimulus appeared to the left and right side of the sample with equal frequency, according to a pseudorandom order of presentation that prevented S+ from appearing on the same side more than twice consecutively. Within the local and global matching trials, 16 trials included consistent sample stimuli in which the local and global shapes were identical (Cc, Ss), and 16 trials included inconsistent sample stimuli in which the local and global shapes were different (Cs, Sc), pseudorandomly intermixed so that the same comparison could not be presented more than twice consecutively.

The overall procedure was made as similar as possible to that used with monkeys by Spinozzi et al. (2003). The most conspicuous differences between the two procedures were that, for the monkeys, an extended MTS training, prior to the testing with compound stimuli, was used to convey information about the nature of the task and that each monkey received a total of 96 trials instead of the 32 trials administered to the children. Moreover, the monkeys tested in the Spinozzi et al. (2003) study had received 96 additional trials with rhombi and crosses as stimulus shapes. As stimulus shape did not produce any significant effect in that study and to avoid tiring the children, we did not administer these extra trials to the children.

Data Analysis

All analyses were carried out exclusively on trials featuring stimuli that both monkeys and children had been presented with. Thus, only the 96

trials in which monkeys were presented with squares and circles as stimulus shapes (the same stimulus shapes presented to the children) were included in the analysis. The other trials that the monkeys had received in the study by Spinozzi et al. (2003) and that featured rhombi and crosses as stimulus shapes (and that were not presented to the children in this study) were excluded from the analysis.

To assess whether factors such as age and gender affected children's performance, we performed a mixed (Matching Condition × Stimulus Consistency × Age Group × Gender) analysis of variance (ANOVA), using percentages of correct responses as the dependent measure. Matching condition and stimulus consistency were the within-subject factors, and age group (younger: younger than 4 years old, $n = 6$; vs. older: 4 years or older, $n = 5$) and gender were the between-subjects factors. Readers can refer to Table 1 for more detail about age and gender of individual children.

We then carried out a second 2 × 2 × 2 (Matching Condition × Stimulus Consistency × Species) mixed ANOVA on percentages of correct responses to compare the performance of children and monkeys in the different conditions and explore possible interactions between the different factors. The use of two different analyses was necessary as the age and sex factors were not applicable to the monkeys, because they were all adult subjects, and with only 3 subjects it was not considered appropriate to split the sample on the basis of the sex of the animals. Moreover, as response time was not recorded for the monkey sample (Spinozzi et al., 2003), a time analysis could be carried out on the data obtained from the children only. This consisted in a 2 × 2 (Matching Condition × Stimulus Consistency) repeated measures ANOVA.

In all the analyses, we carried out post hoc comparisons using Tukey's honestly significant difference (HSD) test. Considering the relatively small number of subjects, we calculated an estimate of effect size (partial η^2) for all the significant main effects observed in the ANOVA.

Table 1
Individual Percentages of Correct Responses for Children and Monkeys Recorded in Each Condition of Experiment 1

Subject	Sex	Age	% correct			
			Local		Global	
			Consistent	Inconsistent	Consistent	Inconsistent
Human						
1	M	35	75.0	62.5	87.5	87.5
2	M	37	100.0	100.0	100.0	100.0
3	M	40	100.0	100.0	87.5	100.0
4	M	43	75.0	100.0	87.5	100.0
5	F	46	100.0	100.0	100.0	87.5
6	F	47	100.0	100.0	100.0	100.0
7	F	48	100.0	100.0	100.0	100.0
8	M	48	100.0	100.0	100.0	100.0
9	F	49	75.0	62.5	100.0	100.0
10	M	50	100.0	100.0	100.0	100.0
11	F	55	100.0	100.0	100.0	100.0
		<i>M</i>	93.2	93.2	96.6	97.7
		<i>SD</i>	11.7	15.2	5.8	5.1
Monkey						
Pepe	M		91.7	87.5	62.5	79.2
Pippi	F		100.0	87.5	75.0	70.8
Gal	M		95.9	100.0	70.9	62.5
		<i>M</i>	95.9	91.7	69.5	70.8
		<i>SD</i>	3.4	5.9	5.2	6.8

Note. Age is presented in months. M = male; F = female.

Results

Accuracy Scores

In the MTS training phase, 11 children achieved the criterion of three consecutive correct responses in the first three trials, showing that they immediately understood the MTS procedure. Two children failed to reach the criterion of three consecutive correct responses in the MTS training phase during the presentation of 16 trials and were excluded from the study.

The percentage of correct responses observed for children and monkeys in the four conditions featuring hierarchical stimuli are reported in Table 1. The apparatus and the procedure adopted proved effective in allowing both children ($M = 95.17\%$ correct, $SD = 9.43\%$) and monkeys ($M = 81.96\%$ correct, $SD = 6.52\%$) to perform at a very high level of accuracy overall.

The $2 \times 2 \times 2 \times 2$ (Age Group \times Gender \times Matching Condition \times Stimulus Consistency) mixed ANOVA conducted on the percentages of correct responses observed in children failed to reveal any significant effect for age, $F(1, 7) = 0.627$, $p > .10$ (older = 96.9%, younger = 93.1%); gender, $F(1, 7) = 0.010$, $p > .10$ (male = 95.0%, female = 95.3%); matching condition, $F(1, 7) = 0.670$, $p > .10$ (local = 93.2%, global = 97.2%); or stimulus consistency, $F(1, 7) = 0.590$, $p > .10$ (consistent = 94.9%, inconsistent = 95.5%) on the children's percentage of correct responses. Likewise, the interactions were not significant.

A second $2 \times 2 \times 2$ (Matching Condition \times Stimulus Consistency \times Species) mixed ANOVA was carried out to detect possible differences in performance between children and monkeys. Because age and gender did not yield significant effects in the previous analysis, these variables were not taken into consideration. The ANOVA revealed a significant main effect for matching condition, $F(1, 12) = 8.017$, $p < .05$, partial $\eta^2 = .40$ (local = 93.5%, global = 83.7%); and species, $F(1, 12) = 8.535$, $p < .05$, partial $\eta^2 = .42$ (children = 95.2%, monkeys = 82.0%), but not for stimulus consistency, $F(1, 12) = 0.033$, $p > .10$. Moreover, the Matching Condition \times Species interaction (but none of the other second order or third order interactions) proved significant, $F(1, 12) = 15.826$, $p < .01$. Post hoc comparisons (Tukey's HSD tests) revealed that monkeys' performance was significantly worse in the global compared with the local condition (70.2% vs. 93.8%, $p < .05$), whereas children's percentages of correct choices were similar in both conditions (global = 97.2%, local = 93.2%). Moreover, children outperformed monkeys in the global condition ($p < .01$), whereas the performance of the two species was not significantly different in the local condition.

Response Time Analysis

This analysis could only be carried out on the children sample, as RTs were not collected in the study by Spinozzi et al. (2003). Only latencies for correct responses were included in this analysis. Among the latencies collected for correct responses, outliers, identified as values of three or more standard deviations above the mean, were removed. Seven outliers out of 335 values (2.1%) were identified on the basis of this criterion. The following mean response times and standard deviations were recorded in the different conditions of Experiment 1: local consistent, $M = 2.85$ s ($SD = 1.11$); local inconsistent, $M = 2.98$ s ($SD = 1.15$); global consistent, $M = 2.70$ s ($SD = 0.65$); global inconsistent, $M =$

2.63 s, ($SD = 1.02$). A 2×2 (Matching Condition \times Stimulus Consistency) repeated measures ANOVA did not reveal any significant main effects or interactions. Similar results (i.e., no significant main effects or interactions) were obtained when outliers were included in the analysis.

Discussion

These results indicate that there are interspecies differences between preschool children and capuchin monkeys in their mode of processing of hierarchical visual stimuli. These differences appear to be localized in the ability to process the global shape of hierarchical visual stimuli. This is clearly shown by the fact that the performance of monkeys but not that of children, although above chance in all conditions, deteriorated in the two conditions in which they had to attend to the global shape of the stimuli to make a correct choice. Direct comparisons of the performance of the two species in the different conditions featured in this experiment confirmed that children performed at a higher level of accuracy than monkeys when the global shape of the stimulus had to be taken into account. By contrast, the perceptual skills of the two species seemed to be indistinguishable when the shape of the local elements had to be processed.

As these differences emerged under conditions that enabled both species to perform at a very high level of accuracy overall, they cannot be easily ascribed to different degrees of motivation or understanding of the task requirements, even if the latter were conveyed in different ways to the children (through verbal instructions) and the monkeys (through an extended MTS training).

Experiment 2

Every precaution was taken in Experiment 1 to prevent the testers from involuntarily conveying spurious cues enabling the children to identify the correct location of the teddy bear without having to process the visual stimuli. However, the fact that the children were very accurate in every condition and that, in contrast with monkeys, they did not show any difference in performance among the different conditions raised the concern that perhaps they were able to pick up spurious cues involuntarily conveyed by the experimenters. To rule out this possibility, we therefore carried out a second experiment with a new sample of children.² In addition to trials pertaining to the different conditions presented in Experiment 1, this second experiment featured control trials in which the identity of the visual stimuli made it impossible for the children to identify S+ on the basis of the visual stimuli alone. If spurious cues guided children's choices, they should have been able to perform above chance in these trials.

² This experiment was conducted in response to a reviewer's request. It was thus carried out several months after the completion of Experiments 1 and 3. As it is mainly a control for the replicability of the results obtained in Experiment 1 in conditions in which the possible use of spurious cues by the children was controlled, it seemed appropriate to report it after Experiment 1 and before Experiment 3. As the sample of children originally used for Experiments 1 and 3 was no longer suitable, considering that the children were now several months older and that they had previous experience with the task, a new sample of children was used for this experiment.

Method

Subjects

Twelve children (7 boys and 5 girls; mean age = 43.92 months, $SD = 4.13$ months) from a local nursery took part in the study. None of the subjects had previous experience with the task used in the study. Three more children were included in the original sample, but they were subsequently removed from the study, as they failed to reach the criterion of three consecutive correct responses in a set of 16 identical MTS trials that were used in the training phase before entering the experiment proper (see *Procedure* section).

Stimuli and Apparatus

The stimuli and apparatus were the same as those featured in Experiment 1.

Procedure

The procedure was similar to that used in Experiment 1 for both the MTS training and the global–local test. The only difference was that we presented 16 control trials at the end of each testing session. In these control trials, the two comparison stimuli were identical to each other, which made it impossible for the child to infer the location of the teddy bear on the basis of the MTS rule. In 8 control trials the comparison stimuli were identical to the sample, and in the remaining 8 control trials they were both different from the sample. Eight control trials featured consistent stimuli, and 8 featured inconsistent stimuli. For each control trial, the teddy bear was randomly positioned behind the comparison stimulus presented on the right or on the left. No specific instructions or specific warnings concerning the change in the pairing of the stimuli with respect to the experimental trials proper were given to the child before the presentation of the control trials.

Results

Accuracy Scores

The analysis of response accuracy confirmed the results obtained in Experiment 1. As in Experiment 1, the mixed (Age Group \times Gender \times Matching Condition \times Stimulus Consistency) ANOVA conducted on the percentages of correct responses observed in children failed to reveal any significant main effects or interactions. The overall percentage of correct responses was 86.2% ($SD = 18.2\%$) and was not significantly different from the overall percentage of correct responses observed in Experiment 1, $t(14.96) = 1.57$ (homogeneity of variances not assumed).

Analysis of Control Trials

The mean percentage of correct responses observed in the control trials was 42.19% ($SD = 14.87\%$). A one-sample t test was carried out to assess whether the distribution of scores observed in these trials was significantly different from a distribution with a mean of 50.0%. The test did not yield significant results, $t(11) = -1.82$, $p = .10$. Therefore, it is unlikely that the children were able to identify the correct location of the teddy bear on the basis of spurious information such as cues unintentionally provided by the testers.

Response Time Analysis

As in Experiment 1, the 2×2 (Matching Condition \times Stimulus Consistency) repeated measures ANOVA did not reveal any sig-

nificant main effects. However, a second ANOVA, carried out after outliers had been deleted, revealed a significant main effect for the factor matching condition, $F(1, 8) = 7.187$, $p < .05$ (partial $\eta^2 = .47$), with responses for global trials ($M = 2.26$ s, $SD = 0.42$ s) being performed faster than responses for local trials ($M = 2.52$ s, $SD = 0.61$ s). By contrast, none of the other factors or interactions was significant. As in Experiment 1, outliers were identified as values three or more standard deviations above or below the mean. Sixteen outliers were detected (4.8% of the total number of values). Ten of the 11 children produced at least one extreme value, and none of the subjects produced more than three outliers. Outliers were observed in all the different conditions. As such, they did not seem to be systematically biasing the results.

Discussion

Overall, the accuracy results of Experiment 2 confirm those obtained for children in Experiment 1. In the global–local test, the overall percentage of correct responses observed in the two samples of children was not significantly different. In Experiment 2, children were able to perform at a high level of accuracy in all the different conditions, and no significant differences emerged between global and local trials or between trials featuring consistent and inconsistent stimuli.

The most important results of Experiment 2 are those obtained for the control trials, as the aim of this second experiment was to assess whether children, despite all the precautions taken to prevent them from doing so, could have been able to use spurious cues involuntarily conveyed by the testers to identify the location of the teddy bear. Control trials were added at the end of each testing session and were designed to make it impossible for the children to infer the correct location of the teddy bear on the basis of the properties of the visual stimuli. The fact that children were not able to perform above chance level in these trials allows us to rule out the possibility that they were solving the task on the basis of spurious cues involuntarily conveyed by the testers.

In this second experiment, a global precedence emerged in the response time analysis following the removal of outliers. An ocular inspection of the mean response time observed in Experiment 1 for the global and the local trials (see above) shows that the results were in the same direction there, although they did not reach statistical significance in that experiment. As this effect did not emerge in Experiment 1, it has to be taken with caution at this point. Although it is not very robust, the emergence of a global precedence effect in children is nevertheless of interest, as it provides a further indication that children, in contrast with monkeys, did not find global trials more challenging than local ones. If anything, they were faster when processing these trials compared with those pertaining to the local condition.

Experiment 3

As outlined in the introduction, some studies have found that the density of the local elements seems to play an important role in determining the global or local biases in the processing of hierarchical visual stimuli in children (Duket & Stiles, 1996; Macchi Cassia et al., 2002) and adult humans (Martin, 1979). For example, in tasks requiring the pictorial reproduction of model hierarchical stimuli, the manipulation of stimulus density selectively affected

the ability of 4-year-olds (compared with 6-year-olds and adults) to process the global shape of the stimuli, so that sparse stimuli were more likely to be matched on the basis of their local features (Dukette & Stiles, 1996).

Stimulus density also seems to affect the mode of processing of nonhuman primates. Data obtained with baboons on a visual search task with hierarchical stimuli (Deruelle & Fagot, 1998) revealed that this species showed a local advantage for processing sparse stimuli but no significant global or local advantage for processing dense stimuli. Some of the chimpanzees tested in the same task (Fagot & Tomonaga, 1999) showed an advantage for processing the local shape of sparse stimuli but no advantage for dense stimuli. However, the local advantage of chimpanzees turned into a global advantage when line segments connected the local elements of the sparse stimuli.

In Experiment 3, we used the same logic as in the previous experiments but manipulated the density of the stimuli to assess whether this variable affects the mode of processing of capuchin monkeys and children differently. In particular, on the basis of our first two experiments with children and the results obtained by Spinozzi et al. (2003) with capuchins, we expected that the processing of the global level of the stimuli should be more easily affected by the manipulation of stimulus density in monkeys than in children.

Method

Subjects, Stimuli, and Apparatus

The subjects were the 11 children who completed Experiment 1. The same four compound stimuli (Ss, Sc, Cc, Cs) used in Experiments 1 and 2 served as stimuli in this experiment. However, in this experiment, the density of the stimuli was manipulated so that a *dense condition* featured

global shapes composed of 16 local elements and a *sparse condition* featured global shapes composed of 8 local elements (see Figure 3). The size of the stimuli at both the local and the global level remained the same as in Experiment 1 and 2. The apparatus was the same used in Experiments 1 and 2.

Procedure

Experiment 3 was carried out on a separate day after the completion of Experiment 1. The children were given the same MTS training as in Experiment 1. Then, each subject completed a 32-trial testing session with compound stimuli following the same general MTS procedure used in Experiment 1. Half of the trials featured dense stimuli, and the other half featured sparse stimuli, with each stimulus, dense or sparse, presented eight times as the sample and with consistent and inconsistent sample stimuli intermixed within the trials. The administration of the trials followed a pseudorandom order that prevented the presentation of identical trials more than twice consecutively. Therefore, within a testing session, trials belonging to a particular condition could not appear more than twice consecutively.

To prevent boredom, we presented children a reduced number of trials compared with the monkeys tested by Spinozzi et al. (2003; Experiment 3), which received a total of 256 trials. The stimuli as well as the number of subconditions presented were identical for children and monkeys.

Data Analysis

In this experiment, the 32 trials presented to the children and the 256 trials presented to the monkeys by Spinozzi et al. (2003) featured exactly the same stimulus shapes. Therefore, the full data set collected for children and monkeys was included in the analysis. The percentage of correct responses observed in the different conditions was used to compare the two species.

The statistical tests used to analyze the results of this experiment were the same used in Experiment 1, with the exception that stimulus density was used as an additional within-subject factor in the ANOVAs.

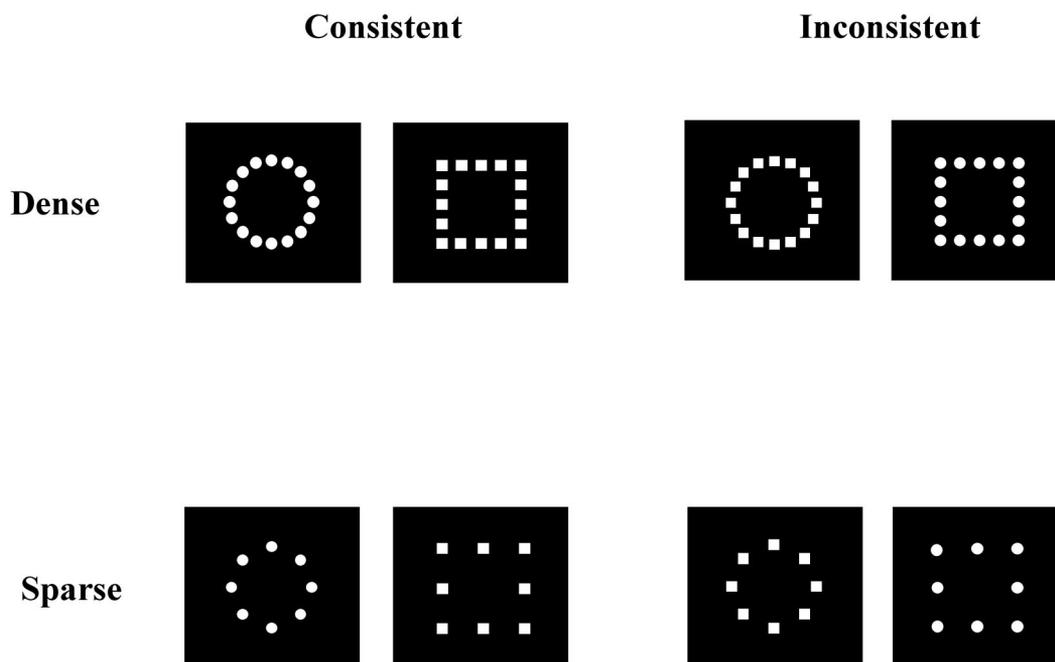


Figure 3. The eight stimuli used in Experiment 3

Results

Accuracy Scores

Overall, children performed at a high level of accuracy in all the different conditions of this experiment. Monkeys in the study by Spinozzi et al. (2003) performed at a high level of accuracy in all conditions, with the exception of the global conditions featuring sparse stimuli. The percentage of correct responses recorded for individual subjects in Experiment 3 are presented in Table 2.

The mixed ANOVA carried out on the percentage of correct responses shown by children, with age group and gender as between-subjects factors and matching condition, stimulus consistency, and stimulus density (dense, sparse) as within-subject factors, did not reveal any significant main effects or interactions.

The 2 × 2 × 2 × 2 (Matching Condition × Stimulus Consistency × Stimulus Density × Species) ANOVA, carried out to assess interspecies differences in the mode of processing of hierarchical stimuli, revealed a significant main effect for density, $F(1, 12) = 14.890, p < .01$ (partial $\eta^2 = .55$), with dense stimuli ($M = 92.3\%, SD = 8.0\%$) being responded to at a higher level of accuracy than sparse stimuli ($M = 85.0\%, SD = 6.7\%$), and species, $F(1, 12) = 55.890, p < .01$ (partial $\eta^2 = .82$), with children performing better ($M = 96.3\%, SD = 7.4\%$) than monkeys ($M = 80.97\%, SD = 7.6\%$) overall. The ANOVA revealed a number of significant interactions: Matching Condition × Species, $F(1, 12) = 14.290, p < .01$ (partial $\eta^2 = .54$); Density × Species, $F(1, 12) = 22.730, p < .01$ (partial $\eta^2 = .65$); Matching Condition × Density, $F(1, 12) = 17.530, p < .01$ (partial $\eta^2 = .59$); and Matching Condition × Density × Species, $F(1, 12) = 15.300, p < .01$ (partial $\eta^2 = .56$).

Post hoc analyses (Tukey’s HSD tests) for third order interactions revealed that children’s performance in the various task conditions did not differ significantly (local dense = 93.2%, $SD = 11.4\%$; global dense = 97.7%, $SD = 5.1\%$; local sparse, $M = 95.5\%, SD = 9.6\%$; global sparse, $M = 98.9\%, SD = 3.8\%$; all $ps > .10$). Conversely, monkeys’ performance in the global but not in the local condition was significantly affected by the stimulus sparsity ($p < .01$), with the percentage of correct responses significantly lower for global sparse (57.8%) than for global dense (90.6%) trials. Moreover, a local advantage emerged for sparse stimuli (local = 88.0%, global = 57.8%, $p < .01$) but not for dense stimuli (local = 87.5%, global = 90.6%, $p > .10$).

Comparison of children and monkeys in the different conditions showed a significant ($p < .00$) interspecies difference for the global sparse trials, with children performing at a higher level of accuracy (98.9%) than monkeys (57.8%). The difference between the two species was not significant ($p > .10$) in the global dense condition (children = 97.7%, monkeys = 90.6%).

To assess in more detail the role played in the two species by the density of the stimuli and to assess the extent to which the addition of local elements linearly affected the processing of the local and the global level of hierarchical stimuli, we carried out trend analyses on the percentages of correct responses (consistent and inconsistent conditions combined) observed in the two species in Experiment 3 and the percentages of correct responses obtained in Experiment 1. In fact, in this latter experiment, the subjects faced stimuli of medium density, compared with the dense and the sparse stimulus densities featured in Experiment 3. The results are reported in Figure 4.

Table 2
Individual Percentages of Correct Responses for Children and Monkeys Recorded in Each Condition of Experiment 3

Subject	% correct							
	Dense				Sparse			
	Local		Global		Local		Global	
	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent
Human								
1	75.0	75.0	100.0	100.0	100.0	75.0	100.0	100.0
2	100.0	100.0	100.0	75.0	100.0	100.0	100.0	100.0
3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
4	100.0	75.0	100.0	100.0	100.0	100.0	100.0	100.0
5	100.0	100.0	100.0	75.0	100.0	75.0	75.0	100.0
6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
7	75.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
8	75.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
9	100.0	100.0	100.0	100.0	75.0	75.0	100.0	100.0
10	75.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
11	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
<i>M</i>	90.9	95.5	100.0	95.5	97.7	93.2	97.7	100.0
<i>SD</i>	12.6	10.1	0.0	10.1	7.5	11.7	7.5	0.0
Monkey								
Pepe	81.2	90.6	84.4	93.7	90.6	84.4	68.7	40.6
Pippi	93.7	90.6	84.4	87.5	87.5	87.5	40.6	78.1
Gal	87.5	81.2	93.7	100.0	90.6	87.5	62.5	56.2
<i>M</i>	87.5	87.5	87.5	93.7	89.6	86.5	57.3	58.3
<i>SD</i>	6.2	5.4	5.4	6.2	1.8	1.8	14.8	18.9

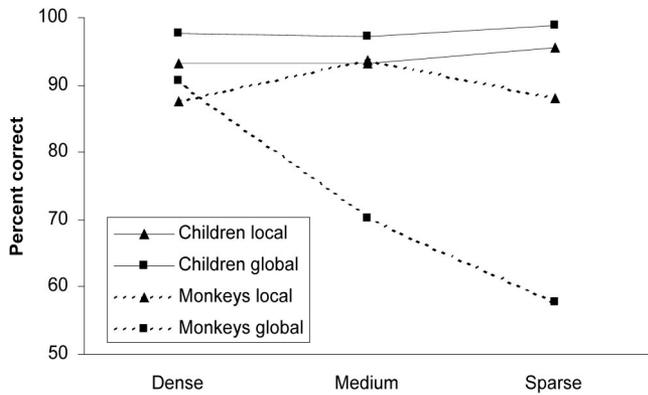


Figure 4. Percentages of correct responses observed in local and global trials, plotted against different levels of stimulus density: dense (Experiment 3, dense condition), medium (Experiment 1), and sparse (Experiment 3, sparse condition).

A significant linear trend, $F(1, 2) = 102.218, p = .01$, emerged only in monkeys' percentages of correct responses in the global trials, showing that the addition of local elements to the hierarchical stimuli facilitated the processing of the global level of the stimuli in capuchins. By contrast, children's performance on global trials was unaffected by variations in stimulus density.

Response Time Analysis

As for Experiments 1 and 2, this analysis could only be carried out on children's data, and only latencies for correct responses were included. Outliers, identified as values of three or more standard deviations above or below the mean, were removed. Only 4 values out of 339 (1.18%) had to be removed on the basis of this criterion.

A $2 \times 2 \times 2$ (Matching Condition \times Stimulus Consistency \times Density) repeated measures ANOVA carried out on the latencies revealed a significant main effect for matching condition, $F(1, 10) = 10.690, p < .01$ (partial $\eta^2 = .52$), with responses in the global trials (2.52 s) being performed faster than responses in the local trials (2.82 s). A significant main effect for matching condition was obtained also when the same analysis was carried out without the removal of outliers, $F(1, 10) = 5.770, p < .05$, (partial $\eta^2 = .37$), with a difference in the same direction for the scores (local trials = 2.85 s; global trials = 2.05 s). None of the other main effects or interactions proved significant, irrespective of whether the outliers were included or excluded from the analysis.

Discussion

The results of Experiment 3 confirm some of the findings of Experiments 1 and 2 and provide further information concerning the effects of stimulus density on the matching performance in the two species. As in Experiments 1, monkeys overall found it more difficult to attend to the global shape of the stimuli compared with the shape of their constituent parts. By contrast, children of the age group considered here seem to be able to process the global and the local levels of the hierarchical stimuli equally well. Density also played a role in the visual processing of monkeys but not in that of

children. Consistent with the finding that monkeys found the processing of the global shape of the stimuli more difficult, the effect of density seemed to be confined to the global trials. When the global shape of sparse stimuli had to be processed, monkeys' performance collapsed to almost chance levels. A direct interspecies comparison showed that children clearly outperformed monkeys in this condition and that their ability to process the global shape of the stimuli was not affected by the sparsity of the local elements. Although a higher percentage of correct responses was observed in children compared with monkeys in the condition featuring dense stimuli, this only approached statistical significance. When subjects had to take the local features into consideration to respond correctly, the performance of both species seemed to be robust across variations of stimulus density.

The response time analysis supports the results observed in Experiment 2 after the removal of outliers by revealing that children were faster when responding to global trials than when responding to local trials.

General Discussion

The results of these three experiments complement those obtained by Spinozzi et al. (2003) and indicate that capuchin monkeys and preschool children process hierarchical visual stimuli differently. The results of Experiment 1 show that although monkeys' level of performance was above chance in all conditions, monkeys were significantly worse at matching hierarchical visual stimuli when the processing of the global shape of the stimuli provided the critical information needed. By contrast, children attended equally well to the local and the global levels of the stimuli. As the performance of children was indistinguishable from the performance of monkeys in the local trials of Experiment 1, the interspecies differences that emerged on the global trials cannot be attributed to spurious ergonomic or motivational factors. By contrast, they seem to express a genuine difference in how the two species process the spatial arrangement of component parts of hierarchical figures.

The results of Experiment 1 also show that, in contrast with adult humans tested in similar conditions (Fagot & Deruelle, 1997), preschool children do not show a global advantage in their accuracy scores but seem instead to direct their attention to both the global configurations and the local features of the hierarchical stimuli when task demands require them to do so. Therefore, they seem to show a pattern of results resembling that observed in chimpanzees, which did not show a clear cut advantage in either the global or the local processing of hierarchical stimuli in visual search tasks (Fagot & Tomonaga, 1999).

In Experiment 2, the pattern of accuracy results obtained in Experiment 1 was replicated with a new group of children. Moreover, in Experiment 2, children were unable to establish the correct location of the teddy bear in trials in which its position could not be inferred on the basis of a matching rule. Therefore, the results of this second experiment allow us to rule out the possibility that children were using spurious cues, conveyed involuntarily during testing by the experimenters, to guide their choices.

The accuracy scores collected in Experiment 3 confirm the basic findings of Experiment 1 and 2. In contrast with children, whose performance was not affected by the level of the hierarchical

stimuli, monkeys found it difficult to process the global shape of the stimuli presented.

Moreover, stimulus density seems to selectively affect monkeys' ability to process the global shape of the stimuli but not their ability to process the local features of the stimuli. This effect is even more evident when data obtained from Experiment 1, which featured stimuli of *medium* density, are included in the analysis. When three levels of stimulus density are analyzed, a linear trend emerges in monkeys' percentages of correct responses on the global trials, with density positively affecting their ability to process the global shape of the stimuli. Preschoolers, by contrast, showed a robust performance across variations of stimulus density. The clearest interspecies difference emerged on the sparse global condition, on which children performed significantly better than monkeys.

A cautionary note is perhaps necessary for interpretation of these latter results exclusively in terms of stimulus density. It is worth mentioning that manipulations of stimulus density obtained by variation in the number of local elements of the stimulus also produce a change in the overall luminance of the stimulus, and it has been shown that an increase in stimulus luminance can make the perception of the global level of the stimulus more difficult (Hughes, Layton, Baird, & Lester, 1984). Therefore, variations in stimulus luminance might also have had an effect in our study. Nevertheless, what emerges clearly from our results is that global processing in monkeys is much less robust than in children.

Overall, monkeys' performance on global trials sharply contrasts with that of children. This difference is emphasized by the analysis of response time performed on children's data. Response time, in fact, can be taken as an additional indication of the relative difficulty or speed of processing of a particular level of the hierarchical stimuli in absence of differences in accuracy between responses in global and local trials. Although no difference in processing time emerged in Experiment 1, in Experiment 2 a first indication emerged that preschool children, similar to adult humans, process the global shape of hierarchical stimuli faster than their local elements. This global precedence effect emerged clearly in Experiment 3, in which the density of the stimuli was manipulated and, most probably, the overall difficulty of the task increased (even just because more conditions with different stimuli were interspersed in a daily testing session). In Experiment 3, children were significantly faster at processing the global shape, compared with their speed of processing of the local elements of the hierarchical stimuli.

This study seems thus to pinpoint a domain in which differences emerge between capuchin monkeys and preschool children. As have those of previous studies involving nonhuman primates, our results challenge the notion of the universality of a global advantage among primates. Moreover, they show that human visual cognition starts to diverge relatively early during cognitive development from that of New World monkeys.

One of the questions raised by these interspecies differences is the identification of the adaptive pressures, which might have favored the emergence of a local advantage in monkeys. Perhaps the active search for very small animal prey, in which prevalently fruit-eating monkeys (as all the species tested so far are) engage for a substantial amount of their time (Hladik, 1979) and which, in tufted capuchin monkeys, has been described as an activity requiring "much diligence and concentration" (Thorington, 1979, p.

105), as well as other activities such as grooming or foraging for seeds, might have favored attentional resources devoted to a fine analysis of individual entities rather than to the spatial configuration into which they are arranged. Chimpanzees, which can derive most of their protein intake from larger prey, such as monkeys and other mammals (Wrangham, 1977), might not experience the same ecological pressure leading to the emergence of a marked local advantage. Ecological considerations apart, these results might be an expression of the relative proclivity shown by different organisms in using the inherent structure of visual material (e.g., the spatial arrangement of local shapes in hierarchical stimuli) to achieve an economic coding of the stimuli.

Finally, from a different perspective, the radical view has been proposed that a single variable, the possession or not of linguistic abilities, accounts for differences between human and nonhuman cognition when effects of ergonomic and peripheral factors can be ruled out (MacPhail, 1987). The extent to which the origin of the differences observed here should be attributed mainly to adaptive specializations, to the effective use of data-reducing processes, or to the influence of other cognitive skills, such as the ability of children to attach a verbal label to different levels of a hierarchical stimulus, has still to be determined.

These hypotheses are, however, certainly within the scope of empirical investigation and call for novel studies in which the ecology of the species under scrutiny and variables such as stimulus size and complexity are manipulated and in which the tasks used for the comparison feature stimulus shapes derived from categories that fall outside the vocabulary of preschool children, so that their visual processing is unlikely to be linguistically mediated.

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