Processing of Contour Closure by Baboons (Papio papio)

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This study investigated the Gestalt law of closure in baboons. Using a computer-controlled self-testing procedure, we trained baboons (Papio papio) to discriminate open versus closed shapes presented on a touch screen with a two-alternative forced choice procedure. Ten baboons (OPEN + group) were trained with the open shapes serving as the positive stimulus (S+), and nine others (CLOSE + group) were trained with the closed shape serving as S+. The OPEN + group obtained higher discrimination performance than the CLOSE + group (Exp 1), but its scores declined when new line segments were added to the stimuli (Exp 2) and after smoothing the end points of the open shapes (Exp 3). The CLOSE + group was less affected by the above manipulations of local stimulus dimension, but its performance was disrupted when the collinearity end points was reduced (Exp 3). Use of a visual search task revealed that the search for an open shape among closed distractors was less attention demanding in baboons than the search for a closed shape among open ones (Exp 4). It is concluded that (1) end lines rather than closeness per se are perceptual primitives for the open versus closed discrimination in baboons, and (2) the relative emphasis on local or configural cues when processing contour closure depends on experiential factors in baboons and is thus subject to interindividual variations.

Keywords: monkey, Gestalt, closure, visual search, search asymmetry

The Gestalt theory is a powerful framework for conceptualizing how perceptual organization occurs. Though developed at the beginning of the 20th century, that theory remains central for contemporary investigators of perception in human adults (Strother & Kubovy, 2006), children (Quinn, Bhatt & Hayden, 2008), and also animals (see Fagot, Barbet & Parron, in press for a review). Founding Gestalt psychologists have attempted to explain how elements of visual displays are grouped to form larger perceptual units. Their main idea was that the perceptual organization reflects the application of several grouping principles (referred to as the Gestalt laws) based for instance on the common fate, good continuation, proximity, and similarity of the stimulus features to be grouped (e.g., Helson, 1933). They further maintained that perceptual grouping is a rigid, preconstructed process, imposed by the activity of the nervous system (Kanizsa, 1980; Köhler, 1929).

Developmental psychologists have tested the hypothesis of a preconstructed perceptual organization in human infants. They found that perceptual organization is not a monolithic phenomenon and have further shown that the Gestalt principles are not all governed by the same underlying mechanisms (see Quinn & Bhatt, 2009 for a review). For example, the principles of good continuation (Quinn & Bhatt, 2005; Quinn, Brown, & Streppa, 1997), lightness similarity (Quinn, Burke, & Rush, 1993), and uniform connectedness (Hayden, Bhatt, & Quinn, 2006) have all been found to be functional by 3 months of age, but the principle of form similarity only becomes functional at 6–7 months of age (Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002). There is also now good evidence that perceptual organization may arise from top-down knowledge of particular objects and object kinds (Needham, 2001; Needham, Duiker, & Lockhead, 2005).

The human and monkey visual systems share many functional properties (e.g., in terms of visual acuity or sensitivity to contrast; e.g., de Valois & de Valois, 1971; Fobes & King, 1982) as well as neurophysiological processes (Merigan & Maunsell, 1993). As a direct consequence of these similarities, comparative studies involving monkeys may efficiently test the hypothesis that the perceptual organization is a “preconstructed” phenomenon. If the human perceptual organization is predetermined by the functional properties of the nervous system, the perceptual organizations of monkeys and humans should be highly similar. This issue has recently generated a great deal of interest in comparative cognition. Many of these studies use the global/local paradigm of Navon (1977).

The Gestalt theory claims that “the whole is different from the sum of its parts.” To assess that idea, Navon (1977) investigated whether the whole visual configurations are perceived before their constitutive parts. To do so, he used hierarchical stimuli structured in a clear two-level hierarchy containing essentially the same information, the global and local levels. They consisted of large letters of many appropriately positioned small letters. Navon found that response times (RT) were faster to global than to local letters and coined that effect “global precedence.” Comparative studies of
human and nonhuman primates using that global–local paradigm
have shown that, in contrast to humans, several primate species
including capuchins (De Lillo, Spinozzi, Truppa, & Naylor, 2005;
Spinozzi, De Lillo, & Truppa, 2003; Spinozzi, De Lillo, & Salvi,
2006), baboons (Deruelle & Fagot, 1998; Fagot & Deruelle, 1997),
macaques (Hopkins & Washburn, 2002), and chimpanzees (Fagot
& Tomonaga, 1999) reliably demonstrate a local rather than a
global precedence. One explanation of this effect is that proximity
grouping is not as efficient in monkeys or apes as it is in humans
(Fagot, Barbet, & Parron, in press). Indeed, increasing the density
of the compound stimuli affects negatively the processing of the
global shapes (De Lillo et al., 2005) or reduces the local advantage
(Deruelle & Fagot, 1998; Fagot & Deruelle, 1997; Fagot & To-
monaga, 1999; Spinozzi et al., 2003), but in that case, animals
showed no reliable advantages for either stimulus level (but see
Neiworth, Gleichman, Olinick, & Lamp, 2006). Comparative in-
vestigations therefore suggest human/nonhuman primate differences
in global precedence and a reduced proficiency for proximity
grouping. A reduced sensitivity to grouping cues has also been
reported in other nonhuman species, such as rats (Kurylo, Van
Nest, & Knepper, 1997; Kurylo, 2008) and Australian sea lions
(Burke, Everingham, Rogers, Hinton, & Hall-Aspland, 2001) in
tasks featuring bistable arrays of dots.

Proximity is one of several grouping cues that animals may
use for object recognition. Unfortunately, very few studies have
investigated these alternative cues in nonhuman primates. Spi-
nozzi, De Lillo, Truppa, and Castorina (2009) aimed to evaluate
the relative weight given to proximity, similarity by shape, and
orientation as perceptual grouping cues in humans and capuchin
monkeys. They compared performance of the two species in a
figure–ground segregation task requiring the participants to iden-
tify the form of a multielement pattern displayed on a background
of other elements. Capuchin monkeys were able to identify the
shape of compound patterns, but differences emerged between
humans and capuchins in their use of shape similarity. From the
authors, these results suggest species differences in the weighting
assigned to different grouping cues.

In that context, the current research focused on the contribution
of one grouping cue which has received very little attention so far
in the animal literature, namely closure. Early Gestalt psycholo-
gists have emphasized the role of closure in perceptual organiza-
tion. They claimed that “If a line forms a closed, or almost closed,
figure, we no longer merely see a line on a homogeneous back-
ground, but a surface figure bounded by the line” (Koffka, 1935,
p. 150). Since that initial theorizing, the contribution of closure
to perception was confirmed by numerous studies involving human
adults (e.g., Elder & Zucker, 1993, 1994, 1998; Kimchi, 2000;
Kovács & Julesz, 1993; Marino & Scholl, 2005; Saarinen & Levi,
1999). It was for instance reported that grouping by closure occurs
early and rapidly during perception (Kimchi, 2000), that shape
discrimination is more precise for closed contours than for open
ones (Saarinen & Levi, 1999), and that the search for a concave
target among convex distractors is efficient for closed stimuli but
inefficient for open ones (Elder & Zucker, 1993).

Investigations of the contribution of closure in the animal liter-
are more scarce. Spinozzi, De Lillo, and Castelli (2004) have
compared performance of humans and capuchin monkeys in an
embedded figure task. They found that humans identified the
different stimulus parts of a sample complex pattern more easily
when the parts can be assembled on the basis of grouping princi-
ples, such as closure and good continuation. By contrast, capuchins
did not rely on these grouping principles in the task but showed
instead a remarkable bias to identify the parts as a set of discon-
ected elements. From that study, however, it would be difficult to
conclude that the monkeys do not process closure and good con-
tinuation as recognition cues, as that processing might have been
masked by the demand of the task in terms of proximity grouping
(for which they have difficulties). In fact, there are reasons to
suspect that closure and good continuations are important cues for
monkeys. In natural setting, the processing of these two cues
appears highly adaptive. Closure and good continuation might for
instance contribute to object recognition despite partial occlusion.
Nonhuman primate species can complete occluded contours (e.g.,
Fagot, Barbet, Parron, & Deruelle, 2006; Sato, Kanazawa, &
Fujita, 1997) or perceive illusory contours from disconnected
elements (e.g., Fujita, 2006).

The current research aims to assess the contribution of closure
and good continuation as cues for object recognition in monkeys.
In four consecutive experiments, we trained and tested baboons to
discriminate stimuli consisting in a single continuous line that was
either open or closed. By using these stimuli, it was possible to
investigate closure processing in experimental conditions that both
minimized and equated the need for proximity grouping.

Experiment 1

Experiment 1 first aimed to test whether baboons can discrim-
inate open from closed shapes presented in the context of a
two-alternative forced choice procedure (2-AFC). Its second goal
was to test postlearning transfer to new open or closed shapes, to
assess a possible use of the discrimination procedure in new
contexts.

Method

Animals and housing. The study involved 19 computer-
trained Guinea baboons (Papio papio), including 11 males (mean
age = 12.54, SD = 11) and eight females (mean age = 9.7; SD = 7.2).
A first set of six baboons (i.e., B03, B05, B06, B07, B11, and
B15) had a very long experimental history involving either a
joystick (e.g., Fagot & Deruelle, 1997; Fagot & Cook, 2006) or a
touch screen for responding (e.g., Fagot & Parron, 2010). These
animals live in the CNRS Primate Facility in Marseille where they
are maintained in small-sized groups of either two (for two groups)
or three baboons. These baboons are kept in large indoor enclo-

cures (18 m²) connected to outdoor (18 m²) compounds. The other
13 baboons belong to a large group of 26 Guinea baboons installed
inside a 670 m² enclosure connected to a housing area. This group
lives within the CNRS Primate Center in Rousset-sur-Arc
(France). These latter baboons include an almost balanced number
of six males (Articho, Barnabé, Bobo, Cauet, Cloco, and Vivien)
and seven females (Angeïe, Arielle, Atlomosphère, Kali, Michelle,
Vanina, and Violette). They had only approximately three months
of exposure with computer experiments at the time of testing
(Fagot & Bonté, 2010).

All baboons are marked by two biocompatible 1.2 × 0.2 cm
radio frequency identification (RFID) microchips, one implanted
in each forearm. Monkeys are not food deprived. They receive
their daily ratio of monkey chows, vegetables, and fruits once a day in the housing area, often at 5 p.m. but at 9 a.m. during the week-ends. Water is continuously available by water dispensers installed in the enclosure and housing quarters. All monkeys were familiar with the automatic learning device for monkeys (ALDM, see Fagot & Bonté, 2010; Fagot & Palleressompoule, 2009; Fagot & Parron, 2010) used for testing. This device is described below.

**Apparatus—ALDM test system.** The experiment used ALDM test systems which are new technical devices allowing the test of the baboons on a voluntary basis, while maintained in a social group, and on a 24-hour schedule. Each ALDM test system consists in a freely accessible test chamber (.7 \times .7 \times .8 \text{ m}). The innermost front side of the test cage is fitted with a .7 \times .7 \text{ cm} view port and two .8 \times 5 \text{ cm} hand ports. The view port allows vision of a 19-inch 1024 \times 768 pixel definition liquid crystal display (LCD) touch monitor installed at eye level 25 cm from the view port. Introducing one hand through one hand port permits actions on the touch screen. Two antennas are fixed around each hand port. They automatically read the identity (ID) number of each participant when it introduced one of its forearms through one of the two arm ports. Numeric identification signals from the forearm tags serve as input for the computers to trigger the presentation of the stimulus and to assign behavioral measures (stimulus choices and RTs) to each participant. The equipment is controlled by a test program developed by the second author using Eprime language (V 1.2, Psychology Software Tools, Pittsburgh, PA). The main feature of this program is to allow independent tests regimen for each baboon, irrespective of the order in which each baboon spontaneously enters the test booth and, for the larger group of baboons, which ALDM test system it is using. Grains of dry wheat are used as reward. They are delivered inside the ALDM monkey area by a homemade food dispenser fixed atop the system.

A total of 13 ALDM systems were used for the current research. Three of them were installed within the outdoor enclosure where the three small-sized groups live (Marseilles’ groups). The other 10 were used by the larger group (Rousset’s group). The 10 latter test systems are installed inside two 32-m² test rooms, five in each test room, and are freely accessible from the enclosure by way of opening made in the wire mesh of the enclosure. More technical details regarding the equipments and their implementation are provided in Fagot and Paleressompoulle (2009) and Fagot & Bonté (2010).

**Stimuli.** Figure 1 (panel a) shows examples of the stimuli. They consisted in random shapes made of a six-pixel-thick yellow line presented on a black computer screen. As illustrated in Figure 1 (panel a), there were two kinds of shapes: polygonal shapes and curvilinear. Each shape was constructed in both an opened and a closed version. The open shape contained a single 30-pixels-wide gap randomly located on the contour of the stimulus. Gaps in these stimuli were neither located in vertex of polygonal shapes nor at points of high degree of change in the curvilinear shapes, because these features are particularly important for object perception (Attneave, 1954). The closed shape contained no such gaps. All stimuli were 15.3 \times 15.3 \text{ degrees of visual angle} (200 \times 200 \text{ pixels}). A total of 120 (60 polygonal and 60 curvilinear) shapes were used for the learning and testing phases of Experiment 1.

**General procedure.** A 2AFC procedure was used. A trial started when a baboon introduced its left or right forearm through one of the two arm ports. That procedure identified the participant and loaded the parameters of the trials assigned to it. Two stimuli appeared on the touch screen after the identification period, one on the left of the screen and one on its right, separated by 450 pixels. The two stimuli used in each trial had an identical overall shape, but one of them contained a gap randomly located on its contour and was therefore an open stimulus. The other one was closed. One of the stimuli was designated as the positive (S+) stimulus, and the other was the negative (S−) stimulus. The left-right location of S+ and S− were counterbalanced. The baboon had to select S+ by

![Figure 1](image-url)
touching the screen. Correct responses delivered a food reward. Incorrect responses were followed by a 3-s timeout during which the screen turned green. All trials were followed by a 3-s intertrial interval (ITI) during which the screen remained black. The subject could proceed to the next trial after that ITI period.

**Training and test procedure.** Initial training was required to have the baboons learning the discrimination problem. Two groups of subjects were distinguished during the training period and consecutive test periods. S+ was the closed shape for the first group which comprised nine baboons (Angele, Articho, Atmosphere, Cloclo, Vanina, B03, B05, and B15). This group will hereafter be referred to as the CLOSE + group. The other group (OPEN +) was tested with the open shape serving as S+. It comprised a total of 10 baboons (Arielle, Barnabe, Cauet, Kali, Michelle, Violette, Vivien, B06, B07, and B11). To control for prior experience with computerized tasks, half of the baboons from the Marseilles’ group, which were highly familiar with computerized testing, were assigned to the OPEN+. The other half was assigned to the CLOSE + group.

In the first training phase, the baboons were required to learn the open versus closed discrimination when the stimuli comprised a large gap of 60 pixels in the open figure. Training sessions contained 120 randomly ordered training trials using 80 different stimuli involving both polygons and curvilinear shapes. The gap of the open shape was reduced to 30 pixels in training phase 2. Training sessions at this stage contained 120 trials involving the same stimuli as in the first training phase, but with a reduced gap. Training sessions were repeated until individual performance reached 85% correct or more in three consecutive sessions of each phase.

The testing consisted of 512 trials per baboon, organized into four sessions of 128 randomly ordered trials. Each test session contained 96 baseline trials involving the same stimuli as during training, and 32 probe trials with 32 new S+ stimuli and their corresponding S− version, with their left/right position on the screen counterbalanced. Baseline trials were differentially reinforced. Probe trials were randomly reinforced at a rate (85%) corresponding to the minimal reinforcement rate achieved at the end of training.

**Results**

**Training.** The baboons from the Marseilles’ group required less training sessions (M = 7.67) in phase 1 than the baboons from Rouset (M = 14.69, t(17) = 2.4, p < .05), but this difference disappeared in the second training phase, t(17) = 1.14, p > .05. For the OPEN + group, reaching the training criterion required 10.9 sessions on average (SD = 7.0) in training phase 1 and 7.5 sessions (SD = 9.0) in training phase 2. For the CLOSE + group, training respectively required 14.22 (SD = 6.1) and 26.11 (SD = 2.3) sessions in training phases 1 and 2. A Test group (OPEN +, CLOSE +) by Training phase (phase 1, phase 2) analysis of variance (ANOVA) computed on the number of training sessions to criterion revealed a significant effect of Test group, F(1, 17) = 4.88, p < .04, and a Test group by Training phase interaction, F(1, 17) = 5.43, p < .03. Post hoc Tukey’s tests (p < .05) showed that reducing the gap size in phase 2 affected performance of the CLOSE + group (mean phase 1 = 14.22 sessions, phase 2 = 26.11) but had no detrimental effect for the individuals of the OPEN + group (phase 1 = 10.9 sessions, phase 2 = 7.5).

**Testing.** Trials with RTs greater than 4 s were discarded for statistical analyses because they may either reflect inattention to the task, or a participant change within the ALDM test system during the trial. The baboons demonstrated an excellent accuracy during testing (M = 89.9% correct, SD = 3%). There was no reliable difference between the performance achieved in baseline (mean correct = 90%, SD = 3%) and probe trials (mean correct = 89.8%, SD = 3.0%; paired t test, t(18) = 0.19, p = 0.85). High performance in the probe trials demonstrates a positive transfer to new stimuli.

Statistical analyses were pursued with an analysis of variance (ANOVA) on scores. It used the baboon’s Troop (Marseille, Rouset) and Test group (OPEN +, CLOSE +) as two between-subjects factors, and the Sessions (1, 2, 3, 4) and Shape (polygonal, curvilinear) as two within-subject factors. There were no reliable main effects (all ps > .05) but a reliable Session × Test group two-ways interaction, F(3, 51) = 3.45, p < .024. Post hoc analyses (Tukey HSD tests, p < .05) indicated a higher performance for OPEN + test group than for the CLOSE + group, which was limited to the first test session (OPEN + group: mean Session 1 = 94.2%, SD = 8.7; CLOSE + group: mean Session 1 = 86.3%, SD = 8.6%). There was also a reliable Shape × Test group interaction, F(1, 17) = 4.96, p < .04. The OPEN + group obtained better performance with the curvilinear shapes (M = 92.9% correct, SD = 7.8%) than the CLOSE + group (M = 87.4%, SD = 9.5%; Tukey HSD, p < .05). There were no reliable differences between the test groups when the polygonal shapes were considered (OPEN +: M = 89.5%; SD = 8.8%; CLOSE +: M = 88.9%; SD = 7.4%). None of the other interactions reached significance (all ps < .05).

**Discussion**

Experiment 1 suggests three main conclusions. First, baboons could learn the open versus closed shape discrimination problem, after an average of 7048 trials, and could maintain a performance better than 85% of correct responses on average in probe trials using new stimuli. This transfer of performance in probe trials demonstrates that the discrimination procedures acquired during the training period were not tied to the specific stimuli used in training. Second, although the baboons from Marseille learned the task faster than their counterparts, there were no reliable performance differences between the two groups during the test phase. This finding suggests that the two groups had identical strategies once learning was achieved. Third, the OPEN + group outperformed the CLOSE + group in Test Session 1, suggesting group differences in their processing of the task.

One important characteristic of the open shapes is that they contain line ends that are basic features in shape perception (Julesz, 1984). It can therefore be proposed that the baboons from the OPEN + group paid particular attention to the end points of the lines delimiting the stimulus gap and used a local mode of processing to that aim. Because polygonal stimuli contain acute vertices perceptually similar to the segment end points, this hypothesis explains the reduced performance of the CLOSE + group with these stimuli. By contrast, baboons from the CLOSE + group would be more sensitive to closure as a global cue, rather than the mere
presence or absence of the endpoint processed as local features. Support of this latter hypothesis derives from the second training phase using a reduced gap size in comparison with the first training phase. Baboons from the CLOSE + group required more training sessions in phase two than the OPEN + group. As the number of end points was independent of gap size, this difference suggests that the baboons did not only attend the local properties of the end points to solve the open/closed discrimination problem but also process some aspects of their configuration. Comparison of the performance in the two training phases supports that conclusion, as a reduced gap size increased the difficulty of the task for the CLOSE + group. This phenomenon, which has already been reported in the human literature (Elder & Zucker, 1993, 1994; Gillam, 1975; Hadad & Kimchi, 2006, 2008; Mori, 1997; Treisman & Souther, 1985), suggests that closure was processed in our task as if it were a continuous rather than a binary dimension.

**Experiment 2**

In the previous experiment, end points were present in open stimuli but absent from the closed stimuli. In Experiment 2, short line segments with end points were added to all stimuli to now have end points in both the closed and open stimuli. We hypothesized that if baboons based their discrimination on the detection of line ends, then their performance should deteriorate when these line segments were added, because both S+ and S− now contain end points which are no longer absolute discriminative cues. Another new feature of Experiment 2 is that new line segments were either presented inside or outside the open and closed stimuli. The rationale of this manipulation was that differences between the IN and OUT conditions might indicate that the baboons processed the close shapes as a bounded region, with a clear distinction between its inner parts and outer surrounding elements.

**Method**

**Apparatus and participants.** The ALDM test systems were the same as in Experiment 1.

**Stimuli.** The stimuli used in probe trials are illustrated in Figure 1 (panel b). They were 64 new polygons or curvilinear shapes. Half of them were new forms constructed from the same principle as in Experiment 1. The second half were new open or closed shapes to which two 30- to 40-pixel-long line segments have been added somewhere on their contour. These segments were presented either inside the shapes for 16 of these latter stimuli, or outside it for the remaining 16. The other aspects of the stimuli, for instance regarding their color or visual size, were identical to Experiment 1.

**Test procedure.** The task was in its general principle the same as in Experiment 1. Baboons from the OPEN + and CLOSE + groups were both presented with four test sessions of 256 trials each. Each test session comprised 192 baseline trials involving stimuli used during training and testing of Experiment 1. They also contained 64 probe trials involving the presentation of 32 new stimuli with no end line added (no-added line condition), 16 new stimuli with added lines inside the stimulus (added line IN condition), and 16 other new stimuli with added end lines on the external contour of the stimulus (added line Out). Baseline trials were differentially reinforced. All probe trials using the new stimuli were randomly reinforced at an 85% rate, just as in Experiment 1.

**Results**

Baboons obtained a high performance in probe trials (mean correct = 85.6%, SD = 5.5%). Performance was however higher in baseline trials (mean correct = 92.2%, SD = 3.6%) than in probe trials (paired t test, t(18) = 5.33, p < .001).

We first compared the performance obtained in the no-added and added-line probe trials, without considering the distinction between the IN and OUT line segments. As there were no reliable differences in Experiment 1 between the baboons from Marseille and Rouset, this analysis and the next ones no more distinguished these two groups. As expected, adding line segments to the stimuli disrupted the performance (mean no-added line = 93.4% correct, SD = 8%; mean added line = 77.8%, SD = 13.1%), and more so for the OPEN + group (see Figure 2). An ANOVA considered the Test group (CLOSE + and OPEN +) as the only between-subjects factor, and Test condition (no-added line, added line), the Session (n = 4), and the Shapes (polygon or curvilinear) as the within-subject factor. It revealed a reliable main effect of Test condition, F(1, 17) = 94.36, p < .001, a reliable Test group × Test condition interaction, and a significant three-way Test Group × Test Condition × Shapes interaction, F(1, 17) = 8.16, p < .011, F(1, 17) = 4.81, p < .04, respectively. As shown in Figure 2, adding lines segments to the stimuli affected the performance of the OPEN + group for both polygonal and curvilinear shapes. For the CLOSE + group, this effect was only observed for the polygonal shapes (Tukey HSD, p < .05).

Second, we compared performance when line segments were added inside (IN) or outside (OUT) the shapes. As shown in Figure 3, the location of the added segments affected differently the two

![Figure 2](image-url)
groups of baboons. These differences were tested with ANOVA considering the Group (CLOSE and OPEN) as a between-subjects factor, and the Session (n = 4), Shapes (polygonal, curvilinear), and Location of the added lines (IN, OUT) as within-subject factors. It revealed two reliable interactions. The first one was a two-way interaction involving the factors Test group and Line location, \( F(1, 17) = 5.75, p < .028 \). That interaction was however accounted for by the Session \( \times \) Test Group \( \times \) Location interaction which was also significant, \( F(3, 51) = 4.29, p < .009 \). As illustrated in Figure 3, baboons from the OPEN group performed better with the OUT lines than with the IN lines, and this difference was reliable in Session 3 (Tukey HSD, \( p < .05 \)). The CLOSE group had a reduced performance over sessions in the OUT trials but an increased performance with continuing testing in the IN trials (see Figure 3). From them, the difference between the IN and OUT condition was significant for Session 4 (Tukey HSD, \( p < .05 \)).

Discussion

Two main findings emerged from Experiment 2. First, success rates were reduced when the stimuli contained additional line segments. This effect can be explained by a greater complexity of these stimuli. Interestingly, however, the display of additional segments affected differently the two groups of baboons, as the OPEN group was more disrupted by the added end lines than the CLOSE group. That difference suggests that the weighting assigned to end points was more important for the OPEN than for the CLOSE group. Our second main result is that the behavioral responses of the two groups were differently affected by the location new segments. Although the results were not significant for all sessions, we found in Session 4 that the CLOSE group was more impaired by the lines presented inside the shapes than by the ones presented outside. This effect did not emerge in the OPEN group, which revealed an opposite pattern in Session 3. These differences are consistent with the idea that the CLOSE group paid particular attention to the inner part of the stimuli and presumably processed the close shapes as fully bounded areas.

One limitation of this experiment is that the addition of the new line segments increased the overall complexity of the stimuli, and this factor might have interfered with the findings. Experiment 3 manipulated two additional factors that might contribute to closure processing, in a context where the overall complexity of the shapes is maintained constant.

Experiment 3

The contributions of two new factors were tested in Experiment 3. The first one is the alignment of the end points (collinearity) in the open stimuli. According to the Gestalt principles (Grossberg & Mingolla, 1985; Kirkpatrick, Wilkinson & Johnston, 2007; Quinn & Bhatt, 2009), the alignment should be a salient stimulus dimension that may contribute to the global shape of the stimulus and may therefore control the discrimination between the open and close shape. The second experimental factor is the visual appearance of the line ends that were either sharp or smooth. If baboons based their responses on the presence/absence of sharp end lines, then their performance should deteriorate with the smooth end lines. It was expected that these experimental manipulations would
help to identify the processing strategies adopted by the OPEN + and CLOSE + groups to solve the task.

**Method**

**Participants and apparatus.** The same test systems and baboons from Experiment 1 participated in this experiment, in addition to one 22-year-old female baboon (B08) who had already been trained in the same conditions as for the other baboons in Experiment 1. B08 was assigned to the CLOSE + group.

**Stimuli.** Figure 1 (panel c) illustrates the stimuli. The stimulus set consisted of 64 new polygons or curvilinear shapes, which were drawn considering the same principles as in Experiment 1. The two end points of the open stimuli were either aligned or misaligned, and in addition either sharp or smooth. Smoothing the end point was done using the “blending tool” of Adobe Photoshop. There were 16 open shapes in each alignment (aligned, misaligned) by type of end point (sharp, smooth) condition.

**Test procedure.** It was in its general principle identical to Experiment 1. The OPEN + and CLOSE + groups of baboons were both tested in four test sessions of 256 trials each. Each test session comprised 192 baseline trials randomly intermixed with 64 probe trials (using the 16 probe trials for each condition of alignment × type of end point). These probe trials consisted in one presentation of each new open shape which was paired with the same shape presented in its closed version. The left–right locations of S+ in the baseline and probe trials were balanced across trials. The other procedural aspects of the task were the same as in Experiment 1.

**Results**

The performance was statistically above chance (50% correct) in the probe trials (mean correct = 82.8%, SD = 3.8%, paired t test, \(t(19) = 36, p < .01\)) but it remained below that of baseline trials (mean correct = 94.3%, SD = 2.3%, paired t test, \(t(19) = 9.97, p < .01\)). The performance decrement in probe trials, in comparison with baseline trials, suggests that alteration of the end point properties disrupted the discrimination between the closed and open forms.

Visual discrimination scores are depicted in Figure 4. The alignment of the end point, as well as their visual aspect affected differently the two groups of baboons (see Figure 4). These differences were investigated with an ANOVA on discrimination scores considering the effect of Test group (OPEN+, CLOSE+). Session (\(n = 4\)), End point alignment (aligned, misaligned), End point type (sharp, smooth). There was a main effect of End point type, \(F(1, 18) = 15.16, p < .001\), as well as a main effect of Alignment, \(F(1, 18) = 71.48, p < .001\). These two main effects were however accounted for by two reliable two-way interactions involving the Test group as a factor (Test Group × End point type, \(F(1, 18) = 7.21, p < .05\); Test Group × alignment, \(F(1, 18) = 7.21, p < .015\)). Post hoc comparisons (Tukey HSD tests, \(p < .05\)) showed End point had no detectable effect on the performance of baboons from the CLOSE + group but affected reliably the performance of the OPEN + group. Baboons in this latter group obtained lower performance for the smooth end points, in comparison with the sharp end points (see Figure 4). By contrast, the use of misaligned end points decreased performance levels in both groups, but the performance decline was significantly stronger (Tukey HSD test, \(p < .05\)) for the CLOSE + group than for the OPEN + group.

**Discussion**

This experiment suggests important differences in the way baboons from the OPEN + and CLOSE + groups solved the open/close discrimination problem. Baboons from the OPEN + group proved strongly sensitive to the appearance of the points, which is a local dimension of the stimuli. This effect of end points suggests a featural mode of processing of the task for these subjects. By contrast, the baboons from the CLOSE + group showed no reliable effects of end points, but they were more sensitive to the misalignment of the terminal segments of the open shapes than their counterparts. Findings from this group therefore demonstrate that the animals from that group had an enhanced sensitivity to the configural properties of the stimuli, in comparison with the OPEN + group. In short, the OPEN + group appears more feature-orientated than the CLOSE + group, which pays greater attention to the configural properties of the stimuli.

**Experiment 4**

Experiment 4 used a visual search paradigm to further explore the hypothesis of a qualitative difference in the processing of the task between the OPEN + and CLOSE + groups. This last experiment was inspired from Treisman and Souther (1985). These authors required human adults to search for an open circle among closed circles, or vice versa, in the context of a visual search task. They reported a search asymmetry: the RTs were faster when the
participants had to identify an open circle among closed circles than in the opposite condition (see also Reiffenrath, Heller & Jacobs, 1991). Treisman and Souther (1985) concluded from their findings that two different search procedures mediated target detections in the two tasks. Based on the analysis of the search slopes in the two conditions, they argued that the subjects detected preattentively the line ends of the gap when searching for an open circle among closed distractors. By contrast, they would preferentially attend to the target contour when searching for a closed target. According to the authors, this latter strategy implies an attentional (serial) processing of the display, as revealed by a significant increment of RTs with display size.

Experiment 4 tested whether a search asymmetry similar to Treisman and Souther (1985) could be replicated in baboons. We used the same two groups of baboons as before, which were now tested with a visual search task. In this new study, baboons from the CLOSE + were requested to detect the closed target among a variable number of open shapes serving as distractors. Performance obtained in this task was compared with that of the OPEN + group tested in the opposite situation (open target and closed distractors). The comparative analysis of the search slopes was expected to shed light on the processing of the open and closed stimuli by these two groups.

Method

Participants and apparatus. The same tests systems and baboons from Experiment 1 participated in this experiment, with the exception of both Michelle and B08 who were no longer available for testing.

Stimuli. The stimuli were the same 20 open and closed shapes as in Experiment 1, but their size was reduced to 130 × 130 pixels for a possible simultaneous display of several stimuli on the screen.

Procedure. Each trial started with a yellow cross appearing centrally at the bottom of the screen. This cross served as a fixation stimuli. Touching the cross triggered the display of 1, 2, 4, or 8 stimuli on the screen. As shown in Figure 5, one of these stimuli was the target, the others were distractors. Stimuli and distractors had identical shapes but differed by the presence or absence of a gap in their contour. All stimuli were distributed randomly on an imaginary 4 × 2 grid. To avoid a systematic alignment on the grid, their location was also randomly staggered within each cell of the grid by a maximum of 30 pixels in both axes. In response to these displays, the baboons had to identify the target and to touch it. Touching the target provided a food reward, while an inappropriate selection of one of the distractors delivered a 3-s time out during which the screen turned green. As with the previous experiments, the open shape served as the target for the baboons of the OPEN + group. In turn, the closed shape served as target for the members of the CLOSE + group.

Before testing, baboons were trained during three sessions of 100 trials that used only the target (no distractor). After training, the two groups of baboons were presented with 8 test sessions of 480 trials each. Each test session comprised 120 trials per display size (1, 2, 4, and 8), which were presented in a random order. Both scores and RTs were recorded in each trial. The RTs were defined as the time elapsed between the onset of the test display and tactile contact with one of the stimuli on the screen.

Results

Scores. The number of correct responses per baboon and display size were entered into a Test group (CLOSE+, OPEN+) × Display size (1, 2, 4 and 8) two-way ANOVA. The ANOVA showed a main effect of Test group, $F(1, 16) = 17.37, p < .001$, a main effect of Display size, $F(3, 48) = 64.59, p < .001$, and an interaction between Test group and Display size, $F(3, 48) = 24.99, p < .001$. This latter interaction is depicted in Figure 6a. As shown in that figure, there was a decline of performance with increasing display size that was stronger for CLOSE + than OPEN + group. Post hoc comparisons (Tukey HSD test, $p < .05$) indicated that the baboons from the OPEN + group performed better than the other group with display sizes of 4 and 8.

RTs. Median RTs for correct responses were calculated for each baboon and display size (Figure 6b). They were analyzed considering the Hick’s law (Hick, 1952). That law predicts that decision times should increase linearly when the number of stimuli ($n$) in the display (i.e., number of choices) is converted to bit units.

![Figure 5](image_url). Illustration of the displays used in Experiment 4. The upper figure illustrates a trial with an open target the lower figure shows a trial with a closed target.
using the function $\log_2(n + 1)$. We therefore converted display sizes to bits (display size 1 = 0 bit, display size 2 = 1 bit, display size 4 = 2 bits, display size 8 = 3 bits) and analyzed the linear relations between RT and bits. The slope of the function indicates whether the amount of bits of information interfered with the basic processing cost of the task given by the intercept value.

Least-square best fitting functions offered very good approximations of average median RTs and their variations. In all our analyses, more than 96% of the variance was accounted for by the linear function (96.8% for the CLOSE + group and 96% for the OPEN + group), suggesting that the RTs followed Hick’s (1952) law. The slope of the linear function between RTs and bits was 115 ms/bit ($SD = 28.6$) for the OPEN + group. Interestingly, that slope was reliably steeper (273 ms/bit, $SD = 67.8$) for the CLOSE + group, $F(1, 16) = 41.58$, $p < .001$ suggesting that it was more demanding to search for a closed shape among open distractors than to search for open distractors among closed shapes. The analyses of intercept showed no reliable higher processing cost of the task, $F(1, 16) = 3.76, p < .07$ for the OPEN + (657 ms, $SD = 94$) and for the CLOSE + group (585 ms, $SD = 61$ ms).

An ANOVA assessed the effects of Test group (CLOSE +, OPEN +) and Bits (0, 1, 2 and 3) on median RTs. It showed a main effect of Test group, $F(1, 16) = 8.86; p < .009$, a main effect of Bits, $F(3, 48) = 227.28, p < .001$. The effect of Group revealed faster responses on average for OPEN + than for CLOSE + group. There was also a significant Test group × Bit interaction, $F(3, 48) = 40.23, p < .001$. Post hoc comparisons (Tukey HSD test, $p < .05$) showed that for the OPEN + group, median RTs only differed between the 0, 1, and 2 bit conditions. There was no statistical difference between the 2 and 3 bit conditions. The result was as follows for the CLOSE + group: 0 bit < 1 bit < 2 bits < 3 bits. Moreover, median response times were significantly faster for the Group OPEN + than for the CLOSE + group, for the 2 and 3 bits conditions.

**Discussion**

Experiment 4 allows two main conclusions. First, baboons performing a visual search task showed RTs that followed the prediction of Hick’s (1952) law. That is, there was a positive association between RT and bits of information processing demand, a finding consistent with other reports using related chronometric approaches to the measurement of selective attention (e.g., Deruelle & Fagot, 1998). According to Treisman and Gelade’s (1980) *feature-integration* theory, this pattern of results suggests an attential processing of the displays in both groups of baboons, which likely adopted a serial search strategy to find the target. Second, great differences emerged between the OPEN + and CLOSE + groups, although both groups demonstrated results in agreement with Hick’s law. This difference corresponds to a much steeper slope for CLOSE + group than the OPEN + group. Of the most importance, this difference cannot be accounted for by a speed–accuracy trade-off, as the positive linear relation between RT and bits was found in a context where the baboons showed a performance decrement with increasing display sizes. Considering Treisman and Gelade’s (1980) feature integration theory, this finding demonstrates that it is more attention-demanding for the baboons to locate a closed target among open targets (CLOSE + group) than to find an open target among closed distractors (OPEN + group). Treisman and Souther (1985) reported flat search slopes in humans, when they have to search for an open circle among closed circles, and these authors interpret their findings as showing that line ends were detected preattentively. In our experiment, the search slope of the OPEN + group was not flat, suggesting that the end lines were not detected preattentively by baboons. The reason for this difference might be the complexity of the (curvilinear and polygonal) shapes used in our experiment, in comparison with the circles used by Treisman and Souther (1985).

**General Discussion**

Four experiments were conducted in this research to assess the discrimination of closed from open shapes by baboons. Investigating this issue was considered important in nonhuman primates, because closure is a critical cue in humans for contour grouping and figure-ground segmentation (Elder & Zucker, 1993, 1994, 1998; Hadad & Kimchi, 2008; Kimchi, 2000; Kovács & Julesz, 1993; Marino & Scholl, 2005; Pettet, McKee & Gryswadows, 1998; Saarinen & Levi, 1999). In addition, this issue has received very little attention so far in the animal literature (but see in pigeons, Allan & Blough, 1989; Kirkpatrick, Wilkinson & Johnston, 2007; Spinozzi, De Lillo, & Castelli, 2004). Baboons were requested in our research to discriminate open from closed shapes in the context of two alternative forced choices (Experiments 1–3) or visual search (Experiments 4) protocols. This discrimination problem can be defined in two ways. The participants may first look for the

![Figure 6](image-url)
critical feature distinguishing the open from the closed shape, namely the presence of end points delimiting gap in the contour. Doing so implies a featural mode of processing with an attention focused on the local details of the shape. The alternative strategy is to search and process closeness per se. That mode of processing requires that the attention moves away from features for the processing of the configural properties of the shape.

Whether nonhuman primates preferentially process the featural or configural properties of displays remain a debated issue. On the one hand, there is an abundant literature suggesting that they process in priority the local features in hierarchical stimuli (De Lillo et al., 2005; Deruelle & Fagot, 1998; Fagot & Deruelle, 1997; Fagot & Tomonaga, 1999; Hopkins & Washburn, 2002; Spinozzi et al., 2006; Spinozzi et al., 2003). On the other hand, other studies, mostly using faces, suggest that they preferentially attend to configural stimulus properties (Dahl, Logothetis, & Hoffman, 2007; Parr, Heintz & Akamagwuna, 2006; Parr & Heintz, 2008). Several aspects of our research support the first hypothesis of a local mode of processing, but this support derives mostly from the OPEN + group. First, baboons from the OPEN + group learned the task in Experiment 1 faster than those of the CLOSE + group, suggesting that the stimulus properties defining openness (i.e., end lines) are more salient than those defining closure. Second, though limited to the first experimental session, performance of the OPEN + group exceeded that of CLOSE + group during the test trials of Experiment 1. Third, adding new end lines to the display in Experiment 2 was distracting and rendered detection of the target end lines more difficult. Fourth, degrading the visual properties of the local feature by smoothing the end lines disrupted their discrimination in Experiment 3. Finally, search times were faster on average in Experiment 4 for the OPEN + group than CLOSE + group, indicating that the end lines were rapidly detected by the OPEN + group. All these results raise issues regarding the saliency of closure cues as perceptual primitives in baboons. They suggest that closure is not such a salient dimension for the baboons. This mere result can explain why the baboons preferred to process in priority the end lines defining openness.

In a different perspective, our results might also be considered in light of the feature-positive-feature-negative (FP/FN) effects. Jenkins and Sainsbury (1969) reported an asymmetry in the learning of discrimination problems by pigeons, when the task involved the presence of a distinguishing feature. In FP discrimination problems, a distinctive feature appeared on reinforced trials and was absent on nonreinforced trials, while the reversed rule was applied in FN problems. In this study, the pigeons exposed to FP problems learned the task faster than the other (FN) pigeons (Jenkins & Sainsbury, 1969). These FP/FN effects have been replicated in different species (e.g., rats: Crowell & Bernhardt, 1979; non human primates: Pace, McCoy & Nallan, 1980; humans: Newman, Wolf & Hast, 1980). In our research, the task proposed to OPEN + group can be conceived as a FP procedure, because the contour is only reinforced when presented together with line ends, but nonreinforced when presented alone. Alternatively, baboons from the CLOSE + group were engaged in a FN procedure, because the contour is only reinforced when presented alone and nonreinforced when presented with the line ends. Models of associative learning (Pearce & Hall, 1980; Rescorla & Wagner, 1972) suggest that FP problems should be learned more rapidly than FN problems in these conditions. From an associative perspective, the end lines would acquire excitatory strength, whereas the contour would remain a neutral stimulus for the FP (OPEN + group). For the FN (CLOSE + group), the contour would acquire intermediate excitatory strength, because it is partially reinforced, and inhibitory processes would have to be recruited to counteract its excitatory effect in the negative stimulus. These inhibitory processes explain why FP discrimination problems are easier to acquire than FN problems.

In our study, the OPEN + group outperformed the CLOSE + group when the end points remained unaltered (Experiments 1 and 4). This finding supports the above conceptualization of our tasks as FP/FN discrimination problems, and therefore suggests that group differences can at least be partly accounted for by this effect. However, some data suggest that the CLOSE + group also processed other aspects of the stimuli than the mere presence or absence of end lines. First, when the size of the gap was reduced in Experiment 1, the CLOSE + group required more training sessions than the OPEN + group to reach learning criterion. This effect of gap size indicates that the baboons from the CLOSE + group processed the separation of the two end lines (Treisman & Souther, 1985). Second, change in the end point alignment in Experiment 3 drastically interrupted the performance of the CLOSE + group. This latter result converges with the human literature also showing the importance of good continuation and collinearity in closure processing (Biederman, 1987; Hadad & Kimchi, 2008; Kimchi, 2000; Pettet, McKee, & Grzywacz, 1998). Finally, alteration of the end point properties in Experiment 3 had no detectable effect on the performance of the CLOSE + group, suggesting that the appearance of the distinguishing feature, the end point, was not a critical feature of the task. In sum, the results from OPEN + group converge with a FP strategy, but the FN strategy is not sufficient to account for the findings of the CLOSE + group. It appears clearly that the CLOSE + group processed some configural aspects of the stimuli, such as the proximity and collinearity of the end lines, in addition to their processing of stimulus features.

Finally, it is noticeable that the OPEN + test groups systematically outperformed the CLOSE + group, when the end points remained unaltered. This finding demonstrates that the processing of features is a more efficient strategy, presumably of a lower level of cognitive complexity, than the processing of configural closure. Several lines of research involving humans support the notion that configural processing is of a higher level of cognitive complexity than featural processing. For instance, Mori (1997) demonstrated that the search for a closed target was dependent upon closure information of global configuration. Because this shape property is too complex to be extracted at a low level of visual processing, it was thought to be constructed at a higher level of processing which incorporates primitive features into perceptual representations of shapes and objects (Tversky, Geisler & Perry, 2004). In addition, human brain imaging studies have both reported that feature analysis mostly activate the primary visual areas (Dumoulin & Hess, 2006; Kourtzi & Huberle, 2005), while configural analyses activate associative areas (e.g., Doniger et al., 2000; Sehatpour, Molholm, Javitt, & Foxe, 2006). Contrary to the claim of early Gestalt psychologists, it can be concluded from our study that closure is not a perceptual primitive for baboons, and this conclusion is in agreement with previous reports on closure processing by nonhu-
human primates (Spinozzi, De Lillo, & Castelli, 2004) and humans (Hadad & Kimchi, 2008).

Altogether, an important finding of this research is a systematic difference between the OPEN + and CLOSE + groups in their processing of stimulus closure. This effect was found in Experiments 1–3, which revealed a generally higher performance for the baboons of the OPEN + group. It was furthermore replicated in Experiment 4, demonstrating that it was easier for baboons to detect open shapes among closed distractors than closed shapes among open distractors. From this set of results, we conclude that the mode of closure processing strongly depends on the training conditions and reward contingencies and therefore fluctuates across individuals. This finding is strongly relevant for the comparative literature on global/local processing. The current debate on this issue in nonhuman primates is mostly aimed to provide a definitive yes or no answer to the question “are monkeys global or local processors” (e.g., Fagot & Deruelle, 1997), but this now seems an inappropriate reasoning. A more adequate reasoning is to conceive that their spontaneous tendency to process stimulus features in priority might be flexibly altered in favor of a greater consideration of global cues, depending on the nature of the task and training contingencies.

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