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THE EFFECT OF AMODAL COMPLETION ON VISUAL MATCHING *

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In a series of five experiments, we investigated how amodal completion affects pattern recognition, and tested possible models of processes underlying completion of simple shapes. Inferences about processing models were based mainly upon the comparison of 'same' latencies in a simultaneous matching task. The major result of experiments 1–4 regards two conditions where a complete target had to be matched with a given stimulus region, belonging to a composite comparison pattern. Matching is faster when this stimulus region is amodally completed than when it looks like an incomplete shape. In experiment 5 we compared complete vs incomplete targets, that were either phenomenally or topographically identical to a given region of the comparison pattern. The failure to show any effect of target completeness suggests that phenomenal identity may be as effective as topographical identity.

Introduction

Light cannot provide local information about objects that lie behind opaque surfaces facing a given viewpoint. Every opaque body occludes both a portion of itself (self-occlusion), and a portion of the residual world (hetero-occlusion). Perceptual theory must explain how the visual system overcomes the indeterminacy of occluded surfaces.

The fact that this indeterminacy is actually overcome can be easily recognized. Our visual world does not resemble the $2\frac{1}{2}$-D sketch (Marr

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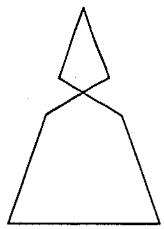


Fig. 1. When crossing lines are covered, a complete triangle appears.

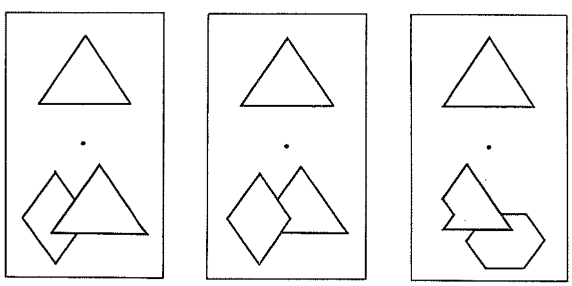
1982); namely, a description of the oriented surfaces which are directly visible. Rather, we perceive solid objects with a somewhat indefinite rear, and we perceive other objects and the background as continuing behind foreground occluders. The phenomenal presence of locally indeterminate parts is called amodal, because it lacks the modal qualities of vision; i.e., the colour and the textural character of surfaces that reflect light to the eye. Thus, amodal completion is a fundamental property of visual perception.

According to Kanizsa (1985), amodal completion should be clearly distinguished from cognitive integration. Indeed, amodal completion is not affected by conceptual knowledge of the distal state of affairs. Two effects illustrate this point. The first, relevant to self-occlusion, is the spoon/egg illusion (Metzger 1963). The convex side of a spoon, fixated monocularly from a short distance, is seen as a solid, heavy, metallic egg. The second, relevant to hetero-occlusion, is a demonstration based on fig. 1 (Michotte et al. 1967). When one puts a pencil over the crossing lines in the middle, a closed regular triangle appears, although no observer would doubt that the crossing lines continue to exist under the pencil.

Kanizsa and Gerbino (1982) have stressed that the covered portion of an amodally completed form is phenomenally objective, whereas a merely imagined addition is phenomenally subjective, and have demonstrated empirically that amodal completion can affect visual properties like size and colour. Several authors have studied the relationships between amodal completion and other perceptual phenomena: Gibson (1979) emphasized the role of kinetic occlusion in contour formation; Sigman and Rock (1974), Rock (1983), Ramachandran and Anstis (1985) explored the influence of perceived occlusion on apparent motion.

Little is known about *how* amodal completion is achieved. Calis and Leeuwenberg (1981) studied the sequential coding of occluded and occluding surfaces, and proposed that the former are tested first, within a search for the optimal interpretation. Rock and Anson (1979) and Reynolds (1981) tested a stage model of the genesis of subjective contours, a phenomenon closely related to figural completion. Using a partial report paradigm, Gerbino (1981) found that it is more difficult to discriminate complete letters from partially covered letters than from comparably truncated letters. This result suggests that immediate memory contains similar representations of complete and amodally completed forms, both of which differ from the representation of truncated forms.

The first experiment reported in the present study regards a comparison of complete, amodally completed, and truncated geometrical figures. The triangle in fig. 2b (bottom) looks more like the triangle in fig. 2a (bottom) than like the one in fig. 2c (bottom), even though the two triangles in figs. 2b and 2c are physically incomplete in the same way. Such experiences of similarity, which are based on the contrast between phenomenal completeness and phenomenal incompleteness, may be operationalized by recording performance in a simultaneous matching task, where subjects are asked to match a single complete triangle with each of the composite patterns shown in fig. 2. This operation represents an instance of the contemporary trend toward testing phenomenological hypotheses by objective experimental techniques (Pomerantz and Kubovy 1981: 426).



a b c

Fig. 2. Three simultaneous matching trials where the subject is required to respond 'same'. Trial *a* is easy because the two triangles are identical. Trial *c* is difficult because the comparison triangle is a truncation of the target triangle. Our experiment will be focussed on performance in trial *b*.

Experiment 1

Fig. 2 illustrates the structure of three trials in which the subject is required to respond 'same'. Although we will state our hypotheses later, the reader might find the following question useful in understanding the motivation of the experiment. We presuppose that the trial shown in fig. 2a is easy, because the target triangle (top) and the comparison triangle (bottom) are identical, and that the trial in fig. 2c is difficult, because the comparison triangle is a modification of the target triangle.

Our experiment is focussed on performance in trials such as shown in fig. 2b.

If amodal completion depends upon categorizing the modal part as a modification of a complete prototype, then the trial shown in fig. 2b should be as difficult as the trial shown in fig. 2c. In both cases the complete triangle has to be matched with an incomplete triangle.

If amodal completion depends upon a transformation within the visual code, then the trial shown in fig. 2b should be as easy as the trial shown in fig. 2a. This hypothesized process of completing the concave region by adding a piece belongs to the general class of viewpoint-dependent transformations, as size and orientation normalizations (Posner 1978). Response facilitation for matching with an amodally completed triangle, with respect to matching with a truncated triangle, should be taken as evidence of the superiority of perceptual integration, revealed by phenomenal completeness, over cognitive integration, involved in categorizing.

In this experiment we used a simultaneous matching task and a 'same/different' paradigm, having both response latency and per cent correct as dependent variables. Our stimuli were composed of elements shown in fig. 3. Each stimulus contained a single complete target (triangle, diamond, hexagon) and a composite pattern.

All composite patterns satisfied two requirements: (i) contours of the two juxtaposed regions always formed T-junctions; (ii) the two segments of common border marked a concavity in the region that was intended to appear as a partially covered form. Both factors favour perceptual stratification of surfaces (Chapanis and McCleary 1953).

All composite patterns derived from three combinations of two basic forms: diamond–triangle, triangle–hexagon, hexagon–diamond. Left/right locations of the two figures were balanced: within the set of 12 mosaics, each form occurred 4 times on the right, 4 times on the left, and was absent 4 times. Regions perceived as amodally completed were used as truncated occluders. Figure pairings were solved by using the triangle intercepted by the diamond as the occluder of the hexagon, the triangle intercepted by the hexagon as the occluder of the diamond, and so on. [1]

The combination of 3 targets by 12 comparison patterns originates a group of 36 trials. The 24 Same trials can be divided into three sets, labelled as follows:

[1] Referring to the spontaneous perceptual outcome, we will conventionally indicate the two figures of the composite pattern by the terms 'occluder' and 'amodally completed figure', or 'foreground figure' and 'background figure'. This is not the consequence of a biased attitude towards the processing of composite patterns. In testing hypotheses, we will consider the possibility that the two juxtaposed regions are matched as such.

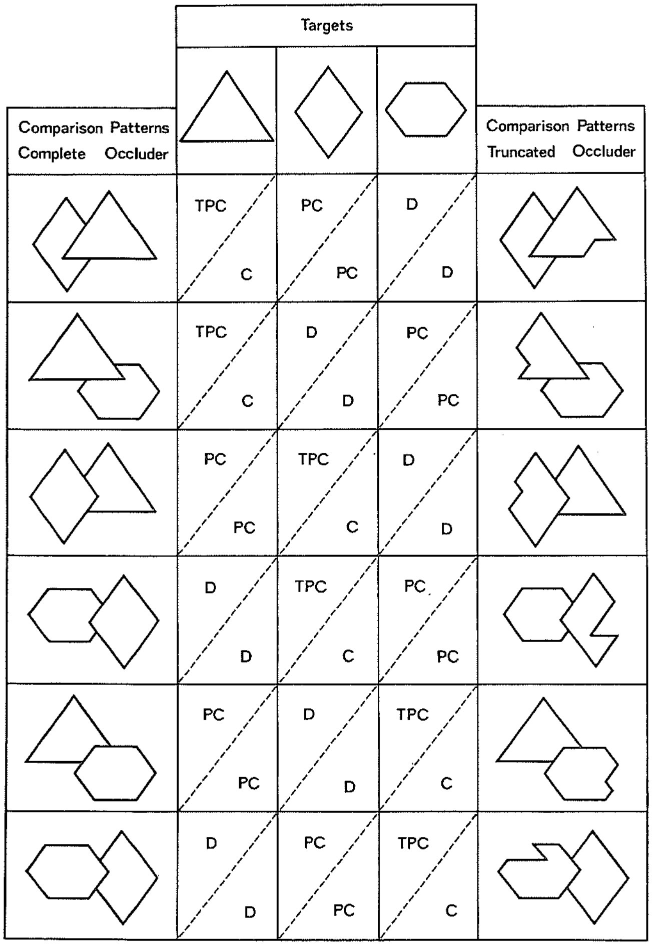


Fig. 3. The whole set of stimuli used in experiments 1–3. Every trial was based on the simultaneous presentation of one of the three complete targets (triangle, diamond, hexagon) and one of the twelve composite comparison patterns. Labels describe the kind of match resulting from the combination of each target with each comparison pattern: positive matches are labelled TPC, PC, and C, according to available identity levels; negative matches are labelled D. In every cell, the upper-left label refers to comparison patterns in the left column (complete occluder), and the lower-right label to comparison patterns in the right column (truncated occluder). See text for full explanation of labels.

TPC: The target and the occluder of the comparison pattern share three kinds of identity: Topographical, because the two forms are congruent regions of the image; Phenomenal, because both forms look complete; and Categorial, because both forms belong to the same figural category.

PC: When the target has to be compared to an amodally completed form, topographical identity is lacking, whereas Phenomenal and Categorial identities are still there.

C: When the concave region looks like a truncated form in the foreground, and covers another region, neither topographical nor phenomenal identities are shared with the target; nevertheless the Categorial identity is still present.

The definition of categorial identity requires two clarifications. On the one hand, the existence of a figural category does not necessarily require the explicit use of a common verbal label. What is needed is the grouping of a complete prototype and a set of modified examplars derived from it. On the other hand, physical truncation does not always generate a region perceived as a truncated form; i.e., as having a shape that is derived from another by subtraction of some peripheral portion. Let us consider a Greek cross, that can be conceived but is not ordinarily seen as a square with four symmetrical indentations. However, the original shape becomes perceivable when the very same region is amodally completed under an occluding surface (several examples are given in Kanizsa and Gerbino (1982)). In order to favour the comparison between PC and C trials, we selected a kind of truncation, and corresponding covering, that does not give rise to form degeneration. We cannot provide a formal definition of the figural properties that guarantee the maintenance of categorial identity. However, we are confident that categorial identity was present in all truncated figures because subjects, during free inspection of stimulus patterns, spontaneously described all truncated figures as triangles, diamonds, and hexagons missing a piece, and easily understood the task, that required to respond 'same' in all C trials.

In Different trials neither figure of the comparison pattern could be matched with the target.

We assumed that performance is a function of the number of identity levels relevant to the task. As to the comparison between the three sets of Same trials, the following hypotheses may be considered.

Hypothesis 1: If all three levels of identity are relevant, then TPC trials should be easier than PC trials, which in turn should be easier than C trials.

Hypothesis 2: If topographical identity is relevant but phenomenal identity is not, then TPC trials should be easier than both PC and C trials, which should not differ one from the other.

Hypothesis 3: If phenomenal identity is relevant but topographical identity is not, then TPC and PC trials should not differ one from the other, and both should be easier than C trials.

In any case, Different trials should be more difficult than Same trials, because a 'different' response requires that both figures of the composite pattern are matched at visual and categorial levels.

During stimulus preparation, we faced a problem in PC and Different trials. TPC and C trials were internally homogeneous. Conversely, because we wanted the whole set of trials to be counterbalanced as to the completeness of the occluder of the composite pattern, half PC and Different trials had a complete occluder and the other half a truncated occluder.

The availability of two subsets of PC trials (PC.c and PC.t) and two subsets of Different trials (D.c and D.t) allowed us to explore how response latencies are affected by the complexity of non-critical figures. Leeuwenberg et al. (1985) hypothesized that form complexity does not affect encoding time. Because response latencies include encoding time, a superiority of PC.c and D.c trials (with respect to PC.t and D.t trials) would allow us to reject this hypothesis.

Method

Subjects

Sixteen students of a visual design school, 16–21 years old, served as subjects.

Stimuli and procedure

Stimuli shown in fig. 3 were generated by a PET computer on a green phosphor monitor. They looked like outline drawings made of densely dotted luminous lines on a dark background. Resolution was 320×200 pixels. Each stimulus configuration (target + comparison pattern) subtended a maximal extent of 5 deg vertically and 3 deg horizontally, at an observation distance of 1 m. The luminances of phosphors and background were 80 and 5 cd/m^2, respectively. A central fixation dot was always visible. The target was always one of the three basic forms (triangle, diamond, hexagon), which had equal areas. The comparison pattern was one of the 12 mosaics. A trial consisted of the simultaneous presentation of both a target and a mosaic comparison pattern, whose positions (above or below the fixation dot) were balanced.

Instructions were given during the presentation of several examples, with long exposure time. It was stressed that a 'same' response was required to all stimuli labelled here TPC, PC, and C. Forty training trials were then given, followed by 192 experimental trials, distributed over two sessions, with an interval of 30 min between them. Ten training trials were given at the beginning of the second session. Experimental trials were presented in a different random sequence for every subject. There were 144 Same trials (48 TPC, 48 PC, 48 C) and 48 Different trials. Subjects pressed response buttons with the index fingers of both hands. Hand-response pairings were balanced across sessions and subjects. Exposure time was 150 msec, and the response time limit was fixed at 2 sec. Trials followed by slow or wrong responses were not reintroduced into the sequence. The computer registered response times with 1/60 sec accuracy.

Results [2]

Overall results are shown in the two right hand columns of table 1. Same trials were faster than Different trials ($t = 12.76$, $p < 0.001$, two-tailed), but equally accurate.

[2] Unless otherwise specified, in all experiments overall significant effects were evaluated by an analysis of variance for repeated measures, and post hoc contrasts between means by a Tukey test. All analyses were performed both on raw scores and on their transformations: logarithmic for response times, and trigonometric for per cent correct. Because analyses on transformed scores never changed significance levels, we will report only F and p values relative to raw scores.

Table 1
Mean response times (RT) in msec, and per cent correct (%), in experiment 1.

	TPC	PC	C	Same	Different
RT	871	914	1145	977	1300
%	94.6	92.2	79.9	88.9	87.2

Data obtained in Same trials were analyzed by a one-way ANOVA for repeated measures on the factor Identity (TPC, PC, C). Latencies were strongly influenced by Identity ($F(2, 30) = 106.97$; $p < 0.001$). Post hoc comparisons of the three means indicate that C trials were significantly slower than both TPC and PC trials ($p < 0.01$). The 43-msec delay of PC vs TPC trials was not significant. Identity also had an affect on per cent correct ($F(2, 30) = 16.75$; $p < 0.001$); this effect is attributable to worse accuracy in C trials.

As to the comparison between the two subsets of PC trials, latencies were shorter when the occluder was truncated. The PC.t–PC.c difference was 53 msec ($t = 2.45$, $p < 0.05$, two-tailed).

The difference between the two subsets of Different trials was not significant (D.c − D.t = 20 msec; $t = 0.828$).

In the next experiment we replicated experiment 1, using other equipment.

Experiment 2

Method

Subjects

Eight paid students of the University of Rome, 18–26 years old, served as subjects.

Stimuli and procedure

Stimuli were photographed from the PET screen. The slides were back projected using a Kodak projector equipped with an electromagnetic shutter. The luminances of stimuli and background were 300 and 5 cd/m^2, respectively. At the viewing distance of 60 cm, stimuli subtended a maximal visual angle of 4 deg horizontally and 7 deg vertically. A chin rest helped maintain a fixed head position. A warning tone preceded the 200-msec stimulus presentation by 500 msec. Stimulus onset started a time limit interval of 2 sec, after which a response was no longer accepted. The intertrial interval was 5 sec long. Subjects responded by pressing one of two keys with either the index or the middle finger of one hand. The choice of the hand and the assignments of fingers to the 'same/different' modalities were balanced across subjects. Response latencies were registered by a timer with msec accuracy. Each subject participated in two sessions: a training session which consisted of 60 practice trials, 36 Same and 24 Different, and the experimental session which consisted of 240 trials, 144 Same (48 TPC, 48 PC, 48 C)

Table 2
Mean response times (RT) in msec, and per cent correct (%), in experiment 2.

	TPC	PC	C	Same	Different
RT	680	705	987	791	1086
%	95.6	96.9	80.7	91.1	89.8

and 96 Different. Hence, the Same/Different ratio was 3 : 2, whereas in experiment 1 it was 3 : 1.

Results

Latencies were shorter than in experiment 1, but their distribution followed an identical pattern (see table 2). The comparison between 'same' vs 'different' mean latencies is highly significant ($t = 18.84$, $p < 0.001$, two-tailed). Percentages of correct responses are equivalent.

Data obtained in Same trials were analyzed by a one-way ANOVA for repeated measures on the factor Identity (TPC, PC, C). The strong effect upon latencies ($F(2, 14) = 94.01$, $p < 0.001$) was due only to the delay in C trials, with respect to both TPC and PC trials ($p < 0.05$). The 25-msec delay of PC vs TPC trials was not significant. The effect of Identity on per cent correct ($F(2, 14) = 29.66$, $p < 0.001$) was due only to the worse performance in C trials.

Within PC trials, latencies were shorter in the PC.t subset. The PC.t − PC.c difference was 76 msec ($t = 3.71$; $p < 0.01$, two-tailed).

The difference between the two subsets of Different trials was not significant (D.c − D.t = 23 msec; $t = 1.405$).

Discussion of experiments 1 and 2

Both latencies and per cent correct obtained in Same trials of experiments 1 and 2 indicate that phenomenal completeness strongly affects matching.

On the one hand, TPC trials were much easier than C trials, as expected from the hypothesis that TPC matches are visual, whereas C matches are categorial. On the other hand, PC trials, in which the critical figure could be amodally completed, were similar to TPC trials and considerably easier than C trials; the match with a complete target is visual when the comparison region looks like a complete but partially covered shape, and categorial when the same region looks like a truncated shape.

Two findings indicate that topographical identity (i.e., literal stimulus identity) is not the crucial property influencing form similarity: (i) the failure to obtain a superiority of TPC over PC trials; (ii) the superiority of PC over C trials, which is a function of phenomenal identity, even though the matching region is topographically the same.

The failure to show any effect of occluder's completeness upon Different latencies (D.c subset equivalent to D.t subset) did not support the hypothesis that form complexity affects encoding time. This finding indirectly validates our interpretation of the poor performance observed in C trials. In fact, even if the difference between D.c and D.t latencies were statistically significant, its order of magnitude could not account for the large delay found in C trials with respect to TPC trials (274 msec in experiment 1, and 307 msec in experiment 2). Therefore, we can reject the hypothesis that the substantial lengthening of C latencies is a mere consequence of the higher complexity of truncated shapes. Rather, it reflects the difference between a visual match (TPC trials) and a categorial match (C trials).

The significant difference between PC.t and PC.c latencies was in the unexpected direction (PC.t trials easier than PC.c trials), confirming that completeness affects matching but not encoding. The non-critical occluder is relevant, plausibly because processing of the composite pattern is sequential, and starts with the foreground figure; this conclusion may contradict the idea, proposed by Calis and Leeuwenberg (1981), that interpretations of background patterns are tested before interpretations of foreground patterns. However, the superiority of the PC.t subset suggests that the presence of a truncated occluder facilitates the selection of the background figure as the one to be matched with the target.

Experiment 3

One could ask whether in experiments 1 and 2 the superiority of PC.t vs PC.c latencies interfered with the lack of statistical difference between TPC and PC latencies. In previous analyses of Same trials, we did not compare PC.c and PC.t latencies with TPC and C latencies, because the relevant groups of trials were not equally numerous (24 trials in PC.c and PC.t subsets, 48 trials in TPC and C sets). Therefore, a simple control experiment was performed, in which the numerosity of the four sets of Same trials (TPC, PC.c, PC.t, C) was equated.

Method

Subjects

Eighteen unpaid undergraduates and staff members of the University of Trieste, 20–35 years old, served as subjects. This group was entirely different from the one used in experiment 1.

Stimuli and procedure

With respect to experiment 1, there were only the following modifications. Subjects were shown a block of 144 trials, made by randomly arranging 48 negative and 96 positive trials (24 TPC, 24 PC.c, 24 PC.t, 24 C). Because we were only interested in comparing latencies in positive matches, the *go/no go* response paradigm was used. Subjects were required to respond by pressing a key with the index of the preferred hand as soon as, and only when, they recognized that the target was present in the composite pattern.

Results and discussion

The false alarm rate was low (3.6%). Table 3 shows the distribution of positive latencies in the four sets of trials. A one-way ANOVA with repeated measures indicates that the experimental treatment had a significant effect on response time ($F(3, 51) = 108.89$, $p < 0.001$). Post hoc comparisons of the four means reveal that C latencies were significantly longer than all the others ($p < 0.01$); and that PC.t latencies were significantly shorter than PC.c latencies ($p < 0.05$). Visual matching is faster than categorial matching, even when the visual selection of the critical figure is slow because the non-critical occluder is complete.

As regards visual matching, the two subsets of PC trials were not statistically different from TPC trials. However, the PC.c–TPC contrast approached the 0.05 level of significance, whereas PC.t and TPC latencies were similar. If amodal completion is the phenomenal counterpart of an encoding process, this pattern of result provided no evidence about its duration, possibly because our matching task lacked the necessary sensitivity. In general, the comparison between TPC and PC trials should take into account the possibility that the target is sequentially matched with the foreground and background figures. A TPC match may be easier than a PC match when the occluder is complete, but they seem equivalent when the occluder is truncated. A truncated foreground figure is judged to be visually dissimilar from the target on the basis of a global property; i.e., completeness. Obviously, in any PC trials the target and the

Table 3
Mean response times (RT) in msec, in experiment 3.

	TPC	PC.c	PC.t	C
RT	801	848	792	1029

occluder of the composite pattern are dissimilar also because they belong to different categories (for instance, triangles vs diamonds); but the superiority of PC.t over PC.c trials suggests that this is not the relevant property at an early stage of matching.

Experiment 4

The superiority of PC over C trials found in experiments 1–3 supports the idea that encoding the composite pattern involves a fast process within the visual code, whose phenomenal counterpart is amodal completion of the background shape. This process is qualitatively different from the classification of a corresponding truncated shape within a given figural category.

Consequently, we can reject the hypothesis that matching occurs at the level of image regions or at the level of any representation shared by truncation and covering. In other words, matching does not operate on the output of a mosaic segmentation, where the very same line plays a double function, being the border of two adjacent forms. This finding is in accordance with the phenomenology of outline drawings, because a line tends to be perceived as the border of only one region.

This conclusion relies upon the assumption that matching occurs at the level of surfaces. But all results so far obtained are also compatible with the hypothesis that matching occurs at the level of outlines. During encoding, the composite comparison pattern is supposedly disambiguated according to the principle of good continuation. However, as fig. 4 illustrates, the disambiguation process is logically decomposable into two distinct stages: (1) the unification/segregation of contour segments, and (2) the completion by amodal continuation. Let us examine them in detail.

(1) The image is analyzed according to a process of unification/segregation: T-junctions are segmented into two perpendicular segments. The collinear portions are unified according to good continuation and contribute to a closed outline, which defines a form that has a modal contour along its entire perimeter. The residual portion of the T contributes to an open outline that partially defines another form. At this stage stratification is not needed, because the unification/segregation process is a planar image analysis.

(2) The residual open contour closes itself amodally, by closure and good continuation, and becomes functionally equivalent to a complete modal surface. At this stage space is partitioned into overlapping planes.

Our visual experience corresponds to the output of the second stage: a mosaic pattern is spontaneously perceived as depicting two overlapping surfaces. But the distribution of latencies obtained in experiments 1–3 is compatible with two hypotheses: (a) matching utilizes the output of the unification/segregation stage, or (b) matching utilizes the output of the completion stage. Although for different reasons, both hypotheses would imply a delay in C trials, with respect to PC trials, and the equivalence of PC and TPC trials. According to hypothesis (a), the target is matched to a complete closed outline in TPC trials, to an incomplete open outline in PC trials, and

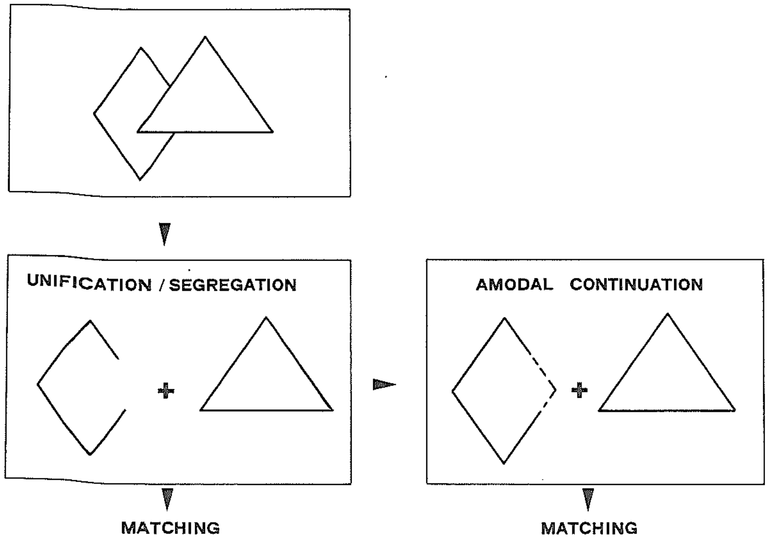


Fig. 4. The disambiguation of a composite pattern can be logically decomposed into two distinct stages: unification/segregation of contour segments, and completion by amodal continuation. In the first stage, T-junctions are segmented according to the principle of good continuation. In the second stage, the open contour is filled-in according to closure and good continuation. The target could be matched with the output either of the first or of the second stage.

to a closed distorted outline in C trials. The additional presence of two contour segments in C trials might delay a positive match, whereas the mere absence of a portion of the critical contour might have no effect. According to hypothesis (b), matching occurs after amodal completion. In PC trials a comparison figure, fully equivalent to the one available in TPC trials, would be generated by a process of contour continuation; in principle, this recoding should introduce a small delay, however difficult to measure. In any case, C trials would be slower than TPC and PC trials because of the truncation.

In the present experiment, comparison patterns were modified in order to allow a choice between such hypotheses. We replicated experiment 1, and used open contours instead of truncated figures. Open contours were obtained by erasing the two outline segments which define the concave truncation in all truncated occluders. In fact, hypothesis (a) has a critical implication: if in PC trials the target is matched to an open contour, then this match should be like a C match in which the critical figure is a foreground open contour.

Method

Subjects

A new group of sixteen unpaid students of the University of Trieste, aged 20–26, served as subjects.

Table 4
Mean response times (RT) in msec, and per cent correct (%), in experiment 4, with open outlines as occluders.

	TPC	PC	C	Same	Different
RT	879	925	1001	935	1204
%	93.4	93.1	88.0	91.5	88.6

Stimuli and procedure

The only difference between this experiment and experiment 1 was the erasing of truncation borders in all truncated occluders (right column of fig. 3).

Results and discussion

Overall results are shown in the two right hand columns of table 4. Same trials were faster than Different trials ($t = 4.50$; $p < 0.001$, two-tailed), but equally accurate.

In Same trials, Identity had a strong effect on latencies ($F(2, 30) = 30.78$, $p < 0.001$). Post hoc comparisons of means indicates that C latencies were significantly longer than both TPC and PC latencies ($p < 0.01$); furthermore, the TPC–PC difference was significant ($p < 0.05$). The analysis of per cent correct indicated that the overall effect of Identity ($F(2, 30) = 7.79$, $p < 0.01$) was entirely due to the worse performance in C trials, with respect to both TPC and PC trials ($p < 0.01$).

We compared experiments 1 and 4 by performing three two-way ANOVAs on latencies, with Experiment as a between-subject factor.

The first ANOVA, having Identity as a within-subject factor, tested the difference between the two distributions of 'same' latencies shown in tables 1 and 4, and illustrated in fig. 5. The main effect of Experiment was not significant ($F = 0.61$). Conversely, both the main effect of Identity ($F(2, 60) = 132.19$, $p < 0.001$) and the interaction ($F(2, 60) = 24.13$, $p < 0.001$) were highly significant. The significant interaction depends on the fact that the two experiments differed in C trials ($p < 0.01$).

The second ANOVA was performed on the two subsets of PC trials, having Occluder (complete, incomplete) as the within-subject factor (see table 5). The incomplete occluder was truncated in experiment 1 and open in experiment 4. Only the main effect of Occluder was significant ($F(1, 30) = 10.12$, $p < 0.01$). This result confirms the superiority of the PC subset with an incomplete occluder.

A third ANOVA was performed on 'different' latencies, in order to control how encoding time was affected by the Occluder (truncated in experiment 1, open in experiment 4). Neither the main effects nor the interaction were significant.

Latencies obtained in Same trials of experiment 4 indicate that subjects find it easier to match a complete target with an amodally completed figure than with an open contour. Such a finding allows us to reject hypothesis (a), according to which matching utilizes the output of the unification/segregation stage, without completion. Rather,

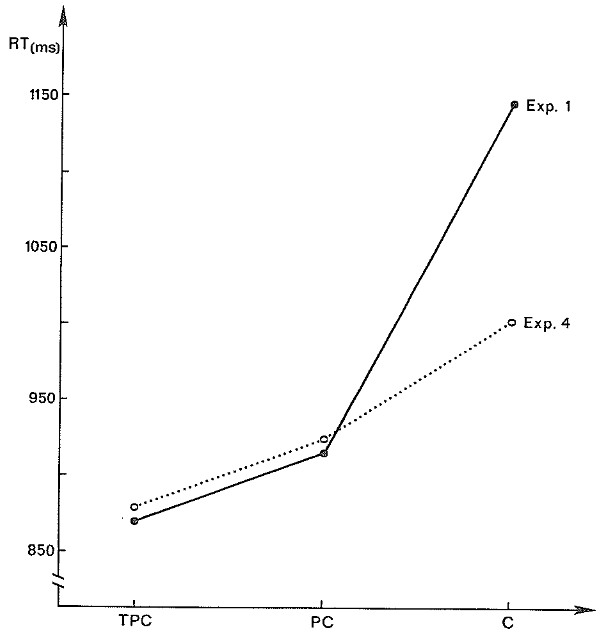


Fig. 5. Graphical representation of TPC, PC, and C latencies in experiments 1 and 4. TPC and PC trials were identical in both experiments; in C trials occluders were truncated in experiment 1 and open in experiment 4.

data fit well into hypothesis (b), according to which matching occurs after completion; i.e., after the 'generation' of the missing piece. On the whole, experiments 1–4 show that perceived completeness of partially covered shapes is mediated by a fast transformation within the visual code, as suggested in the introduction.

Table 5
Mean response times (RT) in msec, for the two subsets of PC trials in experiment 1 (Occluder either complete or truncated) and in experiment 4 (Occluder either complete or open).

PC trials	Occluder	
	Complete	Incomplete
RT		
Experiment 1	938	886
Experiment 4	950	900

Experiment 5

The previous analysis was based upon an implicit assumption, that will provide the focus for the following experiment. Our assumption was that, during the encoding stage, the visual system disambiguates a mosaic pattern containing two adjacent regions by applying a set of local procedures, which generate amodal completion of one region independently from target features. But it is also possible that target features direct the processing of the composite pattern.

Provided that the visual system can generate several solutions of a given pattern, the following two models may be contrasted.

(1) The generation of perceptual solutions is a context-sensitive process. Because the target is relatively simple, its analysis is terminated first and the outcome directs the disambiguation of the composite pattern. Therefore, target features are critical in the encoding of the whole configuration shown in every trial.

(2) Perceptual solutions are sequentially generated in a context-insensitive order. The disambiguation of the composite pattern is not influenced by the target. This model allows two versions, depending on whether the completion solution or the literal solution takes place first. The hypothesis that the completion solution occurs first is supported by the phenomenal immediateness of amodal completion. Conversely, an a priori reason for hypothesizing that the literal solution occurs first is its resemblance to proximal stimulation.

With respect to these models the superiority of PC over C trials in experiments 1–4 is not informative. Even if amodal completion is the secondary product of a context-insensitive disambiguation, PC trials should be easier than C trials, because in the former amodal completion can be automatically generated after the literal solution, whereas in the latter the stimulus cannot support any completion of the occluder (Rock 1983).

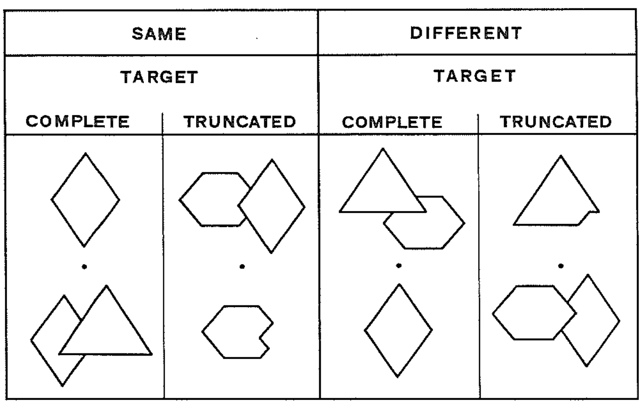


Fig. 6. Examples of each condition of experiment 5.

This experiment was designed in order to choose between above described models. We selected some patterns used in experiments 1–3, and generated four matching conditions, illustrated in fig. 6.

In Same trials, the critical region of the composite comparison pattern was always the one which appears amodally completed. A positive match was based upon both phenomenal and categorial identities when the target was complete, or upon both topographical and categorial identities when the target was truncated. In other words, we compared the relative efficiency of phenomenal vs topographical identities. The superiority of any condition over the other would allow us to reject the context-sensitive model, and favour one version of the context-insensitive model, according to the direction of such a superiority.

In Different trials, there were two parallel conditions, complete vs truncated target. Their comparison will provide further evidence about the possible influence of form complexity on encoding time. In this experiment, complexity might affect target encoding. However, data obtained in experiments 1 and 2 suggest that we should expect no effect.

Method

Subjects

Thirteen paid subjects, 16–28 years old, participated in the experiment.

Stimuli and procedure

The target was either complete or truncated. The critical figure of the composite pattern was always the amodally completed one. In Same trials the truncated target was topographically identical to the uncovered part of the critical figure of the composite pattern. In Different trials the target and the two figures of the composite pattern belonged to different categories. We followed the procedure of experiment 2, using a projection tachistoscope and a timer with msec accuracy. After 48 practice trials, subjects performed 144 experimental trials, equally distributed within the four cells of the Target (complete/truncated) × Response (same/different) design. Subjects were required to respond, as fast as possible, regardless of target completeness.

Results and discussion

Latencies and per cent correct are shown in table 6. Data were analyzed by two-way ANOVAs with repeated measures on both factors. As regards latencies, the only significant effect was the superiority of 'same' over 'different' responses ($F(1, 12) = 76.00$, $p < 0.001$). The analysis of per cent correct revealed a significant interaction ($F(1, 12) = 11.79$, $p < 0.01$); performance in Same and Different trials was equivalent when the target was truncated, whereas it was more accurate in Different trials when the target was complete.

In this experiment we found that matching with a complete target does not differ from matching with a truncated target, in both Same and Different trials. This null result was replicated using a larger set of trials per subject (192 Same and 96

Table 6
Mean response times in msec, and per cent correct (in parentheses), in the four conditions of experiment 5.

	Target	
	Complete	Truncated
Same	790 (79.7)	822 (85.3)
Different	943 (91.0)	963 (87.8)

Different); and also in another experiment where half targets were complete and the other half open instead of truncated.

The failure to show any effect of target completeness on 'same' latencies does not allow us to reject the hypothesis that target features direct the encoding of the composite pattern. However, this finding does not support a two-stage model, in which amodal completion is generated after the literal solution. A response on the basis of phenomenal identity, despite topographical dissimilarity, may be as easy as a response on the basis of topographical identity.

The failure to show any effect of target completeness on Different trials agrees with analogous null results of experiments 1, 2, and 4. The mere presence of an incompleteness in one of the three figures has no effect on encoding time.

Conclusion

Our main finding is that a complete target is matched faster with an amodally completed figure than with a truncated one. As far as form perception is concerned, 'negative' information, represented by the direct evidence about shape truncation, is detrimental; whereas 'missing' information, represented by the local contour indeterminacy associated with perceived covering, is not.

This finding indicates that amodal completion is not categorial in nature. Plausibly, a categorial process underlies matching a complete target with a truncated occluder. But the perceived completeness of forms that look partially covered does not merely correspond to classifying the modally visible part as a figure derived from a complete prototype. Amodal completion is better conceived as the product of an automatic transformation within the visual code, which is so fast that we have been unable to measure its duration. The influence of the non-critical figure of the composite comparison pattern (demonstrated by the superiority of PC.t over PC.c trials) indicates that the foreground figure is matched first. Hence, one should expect that on the whole PC trials are more difficult than TPC trials, in which the critical figure is the occluder. Because this is not the case, then one may conclude that an amodally completed figure is functionally equivalent to a complete figure. This conclusion is of general theoretical relevance because inferences about unobservable processes, drawn by measuring performance in a matching task, confirm the hypotheses suggested by phenomenal observation.

The use of outline drawings required us to test the hypothesis that matching occurs at the level of line segments (experiment 4). Our data do not support this hypothesis and are consistent with findings by Bruno and Gerbino (1986, 1987), who employed solid-colour figures.

On the whole, we found no evidence that incompleteness in itself causes an encoding delay. The failure to show any effect of completeness on 'different' latencies supports the claim (Leeuwenberg et al. 1985) that encoding duration may be constant, despite variations of pattern complexity.

The processing initiated by the simultaneous presentation of a single complete target and of a composite comparison pattern can be modelled in the following way (see fig. 7).

During the encoding stage, the mosaic pattern is disambiguated by automatically generating both the completion solution and the literal solution. During the matching stage, the visual match occurs before the categorial match; within each match, the foreground figure is tested before the background one. Preliminarily, the completeness of the foreground figure is checked. If this is complete, then the visual match with the target is instantiated; if it is successful, a fast 'same' response occurs. If the foreground figure is incomplete (irrespective of whether it is categorially identical to the target or not), visual matching is immediately re-directed towards the background figure. If the latter visually matches the target, because of amodal completion, then an equally fast 'same' response is allowed. If the foreground figure is complete but does not visually match the target, then some time is lost in rejecting it and re-directing matching towards the background figure; hence, a relatively slower 'same' response will follow the visual match with a background figure covered by a complete figure. If the target and the background figure are visually different, then only a categorial match remains possible. A slow 'same' response will follow a successful categorial match between the target and the foreground

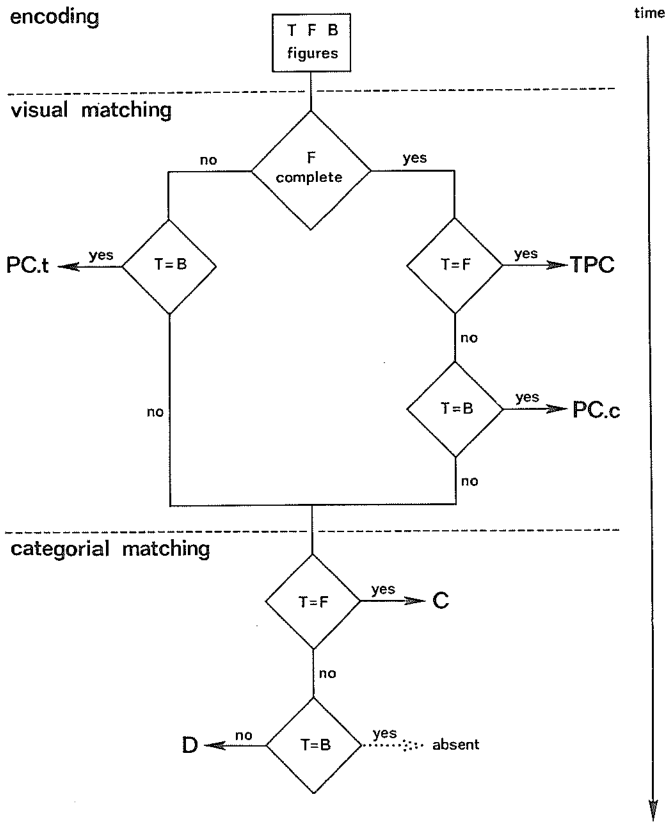


Fig. 7. Flow diagram of matching involved in experiments 1–4. The three figures shown in a trial are labelled as follows: T = Target, F = Foreground, B = Background. Four levels of latencies for correct responses are considered, in the following order (from the fastest to the slowest): TPC and PC.t, PC.c, C, D.

figure. And an even slower 'different' response will terminate the matching stage, if the three figures belong to different categories.

In experiment 5 we tried to specify a model of the visual transformation that supports the experience of amodal completion, and were unable to reject the hypothesis that disambiguation is a context-sensitive process, dependent upon target features. However, Bruno and Gerbino (1986) have found some evidence that the completion solution follows the literal solution, by comparing successive and simultaneous matching tasks. When a truncated target is shown before the comparison pattern, topographical identity is crucial; whereas simultaneous matching is strongly influenced by phenomenal identity.

As a final remark, we want to stress that our experiments were not designed to clarify whether amodal completion is mediated by local factors of organization or by a global tendency towards regularization. Kanizsa (1975) devised situations where maximum symmetry of the amodally completed form is not always achieved, and demonstrated that a relatively local factor, good continuation, seems stronger than global regularity. On the contrary, Buffart et al. (1981, 1983) suggested that all observed outcomes can be explained within Structural Information Theory, which embodies, as a basic assumption, a global tendency towards the minimum information load. Our work was not relevant to this issue, because completions according to good continuation always corresponded to overall regularizations.

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