Perceiving illusory contours: Figure detection and shape discrimination

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We investigate the relationship between illusory figure detection and discrimination of its shape, asking whether these depend on a single, two separate, or two sequential processes. In a simultaneous detection–discrimination experiment, we presented subjects with brief, backward-masked Kanizsa-type patterns consisting of four "pacmen," arranged as if at the corners of a 60-degree parallelogram. Pacman openings were oriented in a quarter of the trials so as to induce an illusory parallelogram. In another quarter, three of the pacmen induced an equilateral triangle. In the remaining half, pacmen were rotated so as not to induce a complete figure. For each trial, subjects reported whether they perceived an illusory figure (detection) and which shape they saw (discrimination), "guessing" the shape even when it was not explicitly perceived. Average detection and discrimination psychometric curves were similar with significantly better-than-chance detection and discrimination beginning at ~100 ms. Nevertheless, we found three patterns of performance, representing different detection–discrimination relationships, suggesting these may be separate processes. Detection was not always followed by correct discrimination, especially for poorer performers. Interestingly there were also cases where discrimination was accurate, even without detection, especially in mid-level performers. One detection–discrimination interaction was that only with explicit detection did shape discrimination use local features (such as the orientation of the fourth pacman in the case of an illusory triangle). We suggest that illusory figure detection and shape discrimination are separate tasks, with their relationship being determined individually.

Keywords: illusory contours, Kanizsa, figure detection, shape discrimination, Reverse Hierarchy Theory


Introduction

A central question regarding visual perception is the seemingly immediate nature of perception versus the known hierarchy of processing stages. One approach in the study of the effective stages of perception is microgenesis, an attempt to halt processing at various times during the process (Flavell & Draduns, 1957; Kimchi, Hadad, Behrmann, & Palmer, 2005; Sekuler & Palmer 1992). Processing stages may be especially approachable for the considerably slower perception of figures that are extracted from sparse cues. Examples include figures that require boundary completion, such as Kanizsa (1979) figures, or contour derivation from indefinite features, such as stereo depth in random dot stereograms (Julesz, 1971). Inducing pacman or random dots necessarily affect low, entry-level processing stages. Figure-ground segregation or depth disparity mechanisms integrate inducer information to represent a separate illusory surface. This surface is perceived to have a shape, and ultimately to be bounded by illusory contours. The subject of the current study is the order of these events and their entry into conscious experience for the case of Kanizsa illusory figures.

Reynolds (1981) pointed out that perception of a Kanizsa form requires lengthy scrutiny (>100 ms), and that what is perceived—inducers or induced figure—depends on available processing time (determined by stimulus-to-mask onset asynchrony, SOA), supporting a multi-stage process with multiple read-out possibilities. In his words, it is still “necessary to chart the temporal course of the percept from the time of stimulus presentation until there is a relatively stable perceptual experience.” Reynolds finds that with extremely short SOA (50 ms) subjects report seeing distinct inducers—presumably without knowing their orientations—but the distracting mask disrupts interaction among them, so that subjects usually report not having seen a triangle. For somewhat longer SOA (75 ms), subjects report seeing a triangle but are at chance reporting its characteristics (curved or straight edged). Only for longer SOA (≥100 ms) do subjects report with some accuracy which triangle was presented. Thus, Reynolds implies that the order of events is detection of inducers and then triangle, followed by detailed triangle shape discrimination. However, he had no
way of determining whether subjects can discriminate shape details without prior detection.

Ringach and Shapley (1996) introduced a novel task paradigm whereby they asked subjects to classify backward-masked illusory Kanizsa figures as “fat” or “thin” in order to quantitatively measure accuracy and derive the degree of boundary completion at various times following stimulus onset. They found two periods of efficient backward masking: local inducer masking, within the first ~117 ms, and global induced-figure masking, 140–200 ms after presentation. This division supports a two-stage hypothesis. However, using only the fat/thin question, they were unable to determine whether illusory figure detection and discrimination of its shape are a single or two separate processes. With early masking, we do not know if Ringach and Shapley’s subjects implicitly perceived pacman presence or orientation or even a figural shape when they were unable to report figural properties.

To overcome these limitations, we asked subjects to report figure detection and then to judge figure shape even when they claimed that they had not consciously perceived a shape at all (for a similar paradigm with word perception, see Reingold & Merikle, 1988). We ask if figure detection and shape discrimination are two separate processes: Are there cases where detection of a figure is not accompanied automatically with discrimination of its shape? Can implicit processing support discrimination judgment even without explicit, reportable figure perception? To answer these questions, we conducted a simultaneous detection and discrimination experiment, measuring illusory figure detection and shape discrimination for each trial—where the discrimination was between illusory triangle and parallelogram shapes (Figure 1).

It is important to clarify what we mean by figure detection, especially when it does not include shape discrimination. In their introduction to the book The Perception of Illusory Contours, Petry and Meyer (1987) define “presence of the illusion” as including three characteristics: (1) sense of a bounded surface differentiated from its surrounding by a property such as brightness; (2) sense of a boundary around the surface; and (3) sense that the edge and surface continue through inducing pattern discontinuities. Thus, when we speak of figure detection, we are referring to a sense that subjects had (and reported) that they had perceived a bounded surface extending among the inducing pacmen. We now ask if this sense is independent of knowledge of the shape of the induced figure.

Stanley and Rubin (2003) found that Kanizsa-type inducers may have two different effects—reflected at different cortical levels: They induce, at lower cortical regions, illusory bounding contours (ICs), and at higher cortical levels (including the Lateral Occipital Complex, LOC; Grill-Spector et al., 1999), perception of an enclosed “salient region” (see also Stanley & Rubin, 2005). They suggest that salient region perception is independent of illusory contour perception and may precede the latter, supplying feedback direction for contour completion (for the notion that higher areas represent a “gist of the scene” before lower areas fill in

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**Figure 1.** Experiment stimulus types and paradigm. Fifty percent of the trials contained complete-figure-inducing patterns (A, B) and 50% did not (C). Among the inducing patterns, half were parallelograms (A) and half triangles (B). Triangles were formed by three pacmen, while the fourth pacman could face IN or OUT (B), as a control for local feature effects. Triangles were upright (A, right) or upside-down (B). Among the patterns that did not induce a complete figure (C), half were non-aligned (with all pacmen facing outward) and half were aligned (inducing illusory lines or partial shapes: Z-aligned, P-aligned, and T-aligned). Note that these examples are all for leftward leaning (inducing or rotated) patterns of pacmen; in actuality, in half of the trials, the patterns were horizontally flipped. (D) Time course of the experiment trial. Presentations were brief and backward-masked for local and global features. Stimulus-to-mask onset asynchrony (SOA) included a fixed 32-ms stimulus duration and varying inter-stimulus interval (ISI). SOA varied from 50 to 200 ms, using a block design (16 trials/block of fixed SOA). Each subject performed 672 trials in 42 blocks.
the details, see Hochstein & Ahissar, 2002). This is consistent with neurons in object-related cortical areas (Kourtzi & Kanwisher, 2001; Malach et al., 1995) being selective for shapes rather than contours.

According to the results of Stanley and Rubin (2003), it is possible that LOC detection of a salient region might be general enough that subjects perceive an illusory figure without being confident of its shape, which would depend on low level features, such as contours. If high cortical levels discriminate between categorically different objects (Farah & Aguirre, 1999; Grill-Spector & Kanwisher, 2005; Hochstein & Ahissar, 2002; Malach et al., 1995) and (illusory) triangles and parallelograms do not differ categorically, then detection of a salient region may not be accompanied by discrimination of its shape.

An intriguing question is whether the opposite event also occurs, i.e., significant shape discrimination even without illusory figure detection. Such a double dissociation between detection and discrimination might suggest that the two processes are more independent than previously proposed rather than simply being two stages in a single process. In this regard, we are interested in local features that may initiate detection of an illusory figure and/or discrimination of its shape.

As is clear in Figure 1, the patterns in a and b induce complete illusory figures. We shall call these “inducing patterns.” The examples of Figure 1C include a variety of pacman patterns, in which the pacman are rotated so as not to induce a complete figure. We shall call all of these “rotated pacman” patterns. They do not induce complete, bounded-surface figures—even though some of them clearly induce illusory contours and even incomplete illusory figures, including, perhaps, more or less noticeable brightness effects. Similarly, we call the pacman in Figure 1A, left a “parallelogram-inducing pattern” and the pacman in Figures 1A, right and 1B, “triangle-inducing patterns” since with extended viewing that is what people generally perceive—even though with our brief and masked presentations, subjects may not perceive these shapes at all.

Positive feedback was provided to subjects with a high tone for correct shape discrimination, when a complete figure was present (even when they did not report detecting the illusory figure and only “guessed” its shape), and with a low frequency tone when they correctly reported absence of a complete figure (irrespective of the guessed shape). The first encouraged shape guessing even when not sure about the presence of a complete figure and encouraged admitting not having detected a complete shape even when quite sure of its shape (perhaps on the basis of other “cues”). In this way, feedback allowed separation of figure detection and shape discrimination responses—even though it did not dictate that they be different. In this way, responses could reflect separate uncertainties in these processes if they were indeed separate processes. Feedback for correct negative (detection) responses encouraged responding similarly to the differently aligned rotated-pacman patterns, though some induced partial shapes or contours and others did not—suggesting to subjects that they should not respond as if they had detected a compete figure if all they perceived was a partial contour alone.

The IN and OUT variants of triangle-inducing patterns of Figure 1B were used to explore the possibility of a single local feature (the fourth pacman) providing a cue for performing the tasks. Similarly, the various alignment types of the rotated pacman patterns of Figure 1C served the purpose of assessing the effect of pacman orientation combinations, adjacent angles, individual illusory contours, or in other words various local cues on detection and discrimination performance.

Thus, in the current study we investigate the relationship between illusory figure detection and illusory shape discrimination—and ask whether these depend on two processes or a single process. In addition if these are indeed two processes, does one depend fully on the other, for example, does discrimination always depend on prior detection.

### Methods

Participants were 12 undergraduate and graduate students aged 23–29, with normal or corrected to normal vision. They were presented with Kanizsa-type patterns (Kanizsa, 1979) consisting of four “pacmen,” arranged as if at the corners of a 60-degree parallelogram, as in Figure 1. Kanizsa-type patterns had a support ratio of 0.39 throughout the experiment.

Stimuli presented in a darkened room on a 17-in. CTX PC monitor occupied 2.5° x 1.8° with subjects at 80 cm distance. The mask occupied 3.5° in diameter. The monitor was set on 50% brightness and 70% contrast.

Before the experiment, subjects were presented with examples of a Kanizsa type parallelogram and a similar triangle. They were asked if they perceived a geometrical shape and what it was in each case to make sure they experienced the illusion. Then they were instructed to focus on the center of the screen, where they would see patterns of 4-pacmen that may or may not induce a shape similar to the examples they had just seen (i.e., a complete geometrical shape in the center of the screen enclosed by illusory contours).

Subjects made 2 responses per trial, indicating (1) whether they perceived a Kanizsa figure (detection) and (2) which shape was present (discrimination)—“guessing” the shape even when it was not explicitly perceived. Following the second response, positive feedback was given as (a) a higher pitch sound, in trials with complete-figure-inducing patterns, for correct shape discrimination (regardless of detection response—to encourage guessing); and (b) a lower pitch sound, in trials with rotated
patterns (i.e., patterns that do not induce complete figures), for correct negative detection response (of course irrespective of guessed shape).

**Results**

Detection of an illusory figure and discrimination of its shape

We analyze characteristics of illusory figure detection and shape discrimination as a first step in investigating their common, sequential, or separate source(s). Detection and discrimination of the Kanizsa figure both improve with SOA, as shown in Figure 2A and Figure 2C, respectively. Fraction correct illusory figure detection is measured as the average of hits for inducing patterns and correct rejections for rotated pacmen trials. On the other hand, shape-discrimination results can only be measured for trials where the pacmen were arranged in such a way that they could induce a complete figure, i.e., similar to the examples of Figures 1A and 1B. For the rotated pacmen cases, though we asked the subjects to guess the shape (in order not to tell them that there was none), there is no *a priori* shape to be compared with the subject response.

Psychometric curves reach 75–80% correct responses at ~100 ms and ceiling at ~150 ms (Figures 2A and 2C). The same data are converted to detectability curves ($d'$; Green & Swets, 1966; Figures 2A and 2C right axes) with similar parameters: crossing $d' = 1$ at ~100 ms and nearing saturation at ~150 ms. The similarity of the performance and $d'$ curves in each case suggest that subjects are not just shifting their criterion with longer SOAs but rather are really getting better at the task. This point is also demonstrated in the ROC graphs of Figures 2B and 2D.

Detection hit rate was calculated as fraction of illusory figure reports in complete-figure-inducing trials and false alarm (FA) rate as fraction of illusory figure reports in rotated pacmen trials. No significant difference was found between the FA rate in all trials with rotated pacmen and in only those with non-aligned pacmen ($F(1,3.91) = 2.77, p = 0.09$). Discrimination hit and FA rates reflect triangle responses in triangle- and parallelogram-inducing trials, respectively (where we arbitrarily chose correct triangle responses as hits). Data point locations relative to the optimal criterion diagonal show a detection conservatism (tendency to answer “no”) for short SOAs, and no consistent discrimination preference for either triangle or parallelogram responses.

Comparing detection and discrimination

The similarity of performance improvement with SOA for detection and discrimination is clearly shown in Figure 3, where we plot detection and discrimination performance together. Note that chance performance for both of these curves is 50% because for discrimination, there are equal probabilities of triangle and parallelogram shapes, and for detection there are equal probabilities for complete-figure-inducing and rotated pacmen stimuli. Discrimination is only slightly below detection, at short SOAs. We calculated the best fit sigmoid for detection and discrimination performance, i.e., percent correct, $F(x)$, as a function of SOA ($x$):

$$F(x) = F_0 + (F_\infty - F_0)/\left\{1 + \exp\left(-k*(x-x_{1/2})\right)\right\}$$  \(1\)

where $F_0$ and $F_\infty$ are asymptotic performances at very short and very long SOA, respectively, $x_{1/2}$ is the SOA where performance is half-way between $F_0$ and $F_\infty$, while $k$ is the slope of the sigmoid curve at $x_{1/2}$ in terms of 1/4 of the
range \((F_{\infty} - F_0)\). Best fit sigmoid parameters were short and long duration asymptotes \((F_0: 42.8 \text{ and } 45.6\%\); \(F_{\infty}: 89.6 \text{ and } 90.0\%\); for detection and discrimination, respectively); midpoint \((x_{1/2}: 74.0 \text{ and } 88.7 \text{ ms})\); and slope at the midpoint \((k^*(F_{\infty} - F_0) / 4: 0.63 \text{ and } 0.74\%/\text{ms})\). None of the differences between detection and discrimination reached significance.

Three patterns of performance

We now ask if the similarity between the detection and discrimination psychometric curves found above is due to these being one and the same process. In Figure 4 we plot individual performance patterns for each of the 12 subjects. There is considerable variability in these curves, which could derive either from noise or from a real difference in performance pattern. Close examination of the individual patterns of Figure 4 revealed three different groups of subjects, as follows: The most direct way of differentiating between these three groups is on the basis of the relationship between detection and discrimination at long SOAs (133–200 ms), i.e., performance asymptote \(F_{\infty}\). The individual relative (discrimination vs. detection) asymptotic performance differences are plotted in Figure 5A (filled symbols). Subjects fall into three groups depending on whether the relative difference is clearly negative,
clearly positive, or is less than ±5%. To assure the reliability of this assignment, we also show in Figure 5A that using either half of the data for each subject (odd or even trials; open symbols) leads to exactly the same grouping.

While it may seem that the individual data fall along a continuum in Figure 5A, in fact, further analysis shows that the groups are very distinct. Other measures, to be discussed below, also reflect distinctions among the three groups. In particular, if we plot the above difference at asymptote versus the subjects’ individual average (discrimination and detection) asymptotic performance, we see very clear clusters for the three groups, as shown in Figure 5B. Thus, the division into groups is reliable and categorical.

Figure 6 shows average detection and discrimination performance for each of the three groups. For group III, detection is superior to discrimination (two-way ANOVA with replication (detection vs. discrimination): mean effect of task ($F_{1,4.75} = 11.13, p < 0.01$). That is, for group III subjects, having detected the presence of an illusory figure does not assure the ability of reporting its shape. For group II, at long SOAs, discrimination is superior to detection ($F_{1,4.26} = 5.64, p < 0.05$)—a surprising result, where subjects are sometimes able to report the illusory shape even without having detected the illusory figure. For group I, there is no significant difference at long SOAs between detection and discrimination ($F_{1,4.41} = 0.74, p = 0.4$). That is, for group I subjects, as soon as they detect the illusory figure they also know its shape. This relationship between detection and discrimination at long SOAs remains valid for all groups regardless whether the detection rate is calculated with all rotated pacmen patterns (aligned and non-aligned) or with non-aligned patterns alone.

As mentioned above, having divided our subjects according to the difference at asymptotic performance parameter, we can then explore the characteristics of their performances, leading to the discovery of additional differences among the groups. In group I (Subjects #4–8 in Figure 4 and Figure 5A), detection and discrimination are nearly equivalent for all SOAs ($p > 0.05$; Figure 6A, left). Group II subjects (#9–12) show a crossover, with detection being better than discrimination at short SOAs ($p < 0.05$); and discrimination better than detection at longer SOAs ($p < 0.05$), as seen in Figure 6A, middle. Group III subjects (#1–3) have discrimination always significantly less good than detection ($p < 0.001$), as demonstrated in Figure 6A, right.

Interestingly, detection for groups II and III are equivalent ($p = 0.23$) and both are significantly worse than group I ($p < 0.01$ and $p < 0.01$, respectively), as shown in Figure 6B, left. On the other hand, discrimination is worse for group III than for group II ($p < 0.05$) and worse for II than for I ($p < 0.01$), as illustrated in Figure 6B, right. Thus, group II is slightly worse than group I in discrimination but much worse in detection. Group III is as good as group II in detection but much worse in discrimination.

The best fit sigmoid parameters in Figure 6C illustrate once more the differences in performance pattern between the groups. The graphs show the between-group change in parameters of both detection and discrimination and the relationship between them. For example, the asymptote, representing the highest performance level, is the best in group I, with identical values for detection and discrimination.
discrimination. In group II, discrimination is better than detection and it is also better than discrimination in group III. Accordingly, in group III, detection is better than discrimination and it is almost equivalent to detection in group II. At the same time, the slope, representing the rate of increasing performance with SOA, is the highest in group I with detection only slightly above discrimination. In group II, there is the largest difference between detection and discrimination slopes, while in group III they are virtually the same.

The different patterns of performance that led us to divide our subjects into three groups raise the question of whether the subjects use different criteria for different tasks. Were some subjects biased to more frequent reports of detection of the illusory figure, or biased to report parallelograms more frequently than triangles, despite the fact that the inducing patterns were equally distributed? If this was the case, what could have caused such a bias?

In Figure 7 we present detection and discrimination ROC curves for each group, separately. For all three groups, the detection graphs reflect consistent near-optimal criterion for longer SOAs, suggesting that the difference between the groups is a real difference in performance level and not just a difference in the criterion chosen. The discrimination ROC curves are also near optimal criterion, except for group III. Subjects in this group have a tendency to respond “parallelogram,” reflected in sometimes reporting “parallelogram” for a triangle-inducing trial, leading to fewer triangle HITs and more parallelogram FAs. Further analysis of this group’s data shows that they were particularly affected by the orientation of the fourth extra pacman (OUT or IN in half of the triangle-inducing trials). This effect of the orientation of the fourth extra pacman is discussed below in the Local feature effect section.

Thus, we found 3 groups of subjects with different patterns of relationship between detection and discrimination. This grouping may reflect subject ability at perceiving illusory contours, at the time of the experiment.

Relating discrimination and detection

If detection and discrimination are indeed separate processes, they may be found separately, i.e., discrimination without conscious detection or detection without accurate discrimination. We address these two outcomes in order.
We were interested in the possibility of an implicit aspect of illusory shape perception. Can there be discrimination without detection? That is, can there be implicit information in the brain about shape sufficient to guide a two-alternative-forced-choice (2-AFC) shape discrimination without explicit awareness of the presence of a figure? For this purpose, we focused our attention on cases of presentation of an illusory figure (disregarding the 50% of trials where there was no illusory figure present), looking separately at trials with detection hits (correctly detected presence of a figure) and misses (not detecting a present figure). Comparison between the rates of shape discrimination in these two cases will give us some idea about illusory shape discrimination with and without explicit detection of the illusory contour figure. Recall that in both cases there actually was an illusory contour-inducing pattern present, and subjects were asked to guess the shape of the figure even when they reported that they had not actually seen a figure.

As illustrated in Figure 8A, the same tendency of improvement with growing SOA appears in shape discrimination with (filled symbols) and without (empty symbols) detection. Without detection, performance is lower than with detection. Nevertheless, it is above chance (50%) at longer SOAs. This suggests that illusory contour figures are processed sufficiently for shape discrimination even when they are not explicitly perceived. There has also been some debate concerning the possibility of

![Figure 7](image)

Figure 7. Detection and discrimination ROC graphs for different SOAs (indicated by symbol fill patterns, as shown in legend) for the three groups. Detection data show almost optimal criterion for all groups (except at the shortest SOAs), as do the discrimination data except for group III. The criterion bias for this group’s discrimination is towards reporting parallelograms even in triangle-inducing trials. As revealed by further analysis, this bias is due to the effect of the fourth extra pacman orientation (see Local feature effect section).

![Figure 8](image)

Figure 8. Inducing trials results, N = 12. (A) Shape discrimination in hit (filled symbols) and in miss (open symbols) detection trials. (B) Illusory figure detection followed by correct (filled) and incorrect (empty) discrimination responses. Note that performance is better for each parameter when the response for the other parameter is correct but is not at chance level even when the response to the other is incorrect. Note that in panel B, chance level is about 12% (i.e., the false alarm rate when the stimuli are rotated pacmen; see Figure 2B). These results support the potential independence of the detection and discrimination mechanisms.
detection without discrimination: When we detect an object are we already aware of its identity or is another step required? This question may be related to the presence of hierarchical steps in perceptual processing.

Figure 8B shows results for detection with and without discrimination. We find that there is a better chance of detection when there is (a following) correct discrimination than when the following discrimination reply is incorrect. While for longer SOA there are more cases of detection with discrimination than detection alone, nevertheless, there are significant numbers of cases of detection without subsequent discrimination. Correct detection is neither a foregone conclusion nor a prerequisite of correct discrimination.

We now look at discrimination and detection with and without each other for each of the 3 groups, expecting that their different levels of performance might be reflected in their use of different detection and discrimination mechanisms. Shape-discrimination results for inducing trials are illustrated in Figure 9. Shape discrimination with detection improves with SOA for all of the three groups (filled symbols). Note that in group I, at SOAs longer than 100 ms, the number of trials in which the subjects discriminated correctly between the illusory shapes but did not detect the illusory figure was insufficient for analysis. Discrimination performance above chance without detection (empty symbols) is evident in group I at 100 ms and in group II for the longer 3 SOAs (133, 167, 200 ms).

The situation for detection not leading to discrimination is well above (12%) chance level for all three groups, for all but the shortest SOA, as shown in Figure 9. Here again we find that the probability of detection without (as with) discrimination rises from group III to II to I. We conclude that there is a separation of detection and discrimination, allowing for discrimination without detection or detection without discrimination in different subject groups.

Local feature effect

We wondered what impact, if any, there was on shape detection and discrimination of the orientation of individual pacmen. There are two cases of interest: First of all, there is the case where there is no complete figure induced, but where the pacmen might be aligned somewhat or not at all. Recall that, as demonstrated in Figure 1C, there are different types of arrangements of the rotated pacmen. Would some alignments provide hints as to the absence of a complete figure? The complement to this question would be that other alignments might lead to a (false) impression of a complete figure, leading to false alarm detection reports. Secondly, when a triangle shape was induced, the orientation of the fourth, uninvolved pacman might also provide some clue as to the triangular-figure induced by the other three (or, equivalently, to the lack of parallelogram figure).

The "extra" pacman in triangle-inducing patterns

Both of our inducing shapes had four pacmen in their pattern. But while all four of them were necessary for inducing a parallelogram, only three were sufficient for a triangle. The extra pacman in this case served another important role: a control for local feature effects on the performance of the two tasks. As a measure for such an

![Figure 9](image-url)
effect, we used the difference of performance in two triangle-inducing types of trials that are illustrated in Figure 1B: Half of the triangle-inducing trials had the extra pacman facing outward (OUT) and the remaining half had the extra pacman facing inwards (IN). Note that either extreme pacman could be the “extra” one for a triangle figure. In addition, there were two possible configurations, with the outlined parallelogram leaning leftward or rightward. Taken together, this means that subjects could not concentrate on only one pacman or spatial location relative to the fixation point for help in determining the shape of the figure.

A mean OUT–IN difference with negative values, as in detection results illustrated in Figure 10 (black bars), means that in OUT-trials our subjects reported seeing an illusory figure less frequently than in IN-trials. This may be due to the fact that rotated pacmen less frequently face outwards.

Turning to the results for the discrimination task, we analyzed separately cases with explicit detection (i.e., preceded by a report of having seen an illusory figure) and cases without detection (Figure 10, gray and white bars, respectively). In both of these cases, the effect is in the opposite direction from that for the detection task: Here the values are positive, suggesting that the OUT orientation of the fourth pacman contributes additional information towards triangle-parallelogram discrimination.

In cases with explicit detection (Figure 10, gray bars), OUT–IN triangle response differences are significantly different than zero for group I ($p < 0.001$) and group III ($p < 0.001$). But in group III the effect is significantly bigger than in group I ($p < 0.01$) and group II ($p < 0.001$). Without detection (Figure 10, white bars), OUT–IN differences do not differ significantly from zero in any of the three groups.

In summary, local feature information supplied by the orientation of the extra pacman had a significant effect on shape discrimination only in trials in which subjects reported detection of an illusory figure. The weakest group in discrimination had the strongest effect of the local feature on discrimination performance. Interestingly, pacman orientation had different effects on detection and discrimination: OUT biased for reporting NO figure, thus making detection worse, while it biased subjects towards reporting a triangle shape, thus improving discrimination. IN had the opposite effects. This dissociation supports our above conclusion that detection and discrimination may be separate processes.

**Effects of pacman orientation and alignment**

**Detection**

We present in Figure 11A the rates of (falsely) reporting presence of an illusory closed figure—for the different rotated pacman alignment types (as in Figure 1C). We expected that any alignment of pacmen might induce contours and thus a sense of a figure, leading to false
alarm detections. However, this was not the case. For both the T- and P-aligned cases, there are no more FA reports of illusory figures than in the non-aligned case. This would support the conclusion that subjects were using presence of a closed or complete figure as criterion of reporting detection and not presence of contours or partial incomplete shapes. Only in the Z-aligned case did pacman alignment produce a significant bias towards more frequent FA reporting of detection of an illusory contour figure (compared with the non-aligned case). What is the source of these extra false alarm detections? We note that this pattern of pacman, with the extreme pacmen mouths facing inward, defines a more bounded central region than do the T- and P-aligned pacman patterns. This bounded region may have occasionally induced a “sense of bounded surface” leading to the false report of an illusory shape. Interestingly, subjects did not report the shape of this surface to be a parallelogram any more than they did for the T- and P-aligned pacman patterns. This bounded region might have occasionally induced a “sense of bounded surface” leading to the false report of an illusory shape. Interestingly, subjects did not report the shape of this surface to be a parallelogram any more than they did for the other cases (Figure 11B). A two-factor ANOVA for detection in the Z-aligned vs. non-aligned trials showed a significant effect for alignment ($F(1,3.9) = 32.562, p < 0.001$) but not for SOA ($F(5,2.28) = 1.98, p = 0.08$) and no significant interaction between them ($F(5,2.28) = 1.95; p = 0.09$).

Similar ANOVA analyses for the alignment of pacman in the T-aligned and P-aligned cases showed that these did not produce significantly more detection FAs than the non-aligned case. Thus, we must conclude that subjects are not simply looking for aligned pacman and reporting detection of an induced figure when perceiving this alignment. Whatever is the cue inducing illusory contours, it does not suffice to induce perception of a figure; it appears that an additional or an alternative process is required for figure detection—related perhaps to the appearance of a bounded enclosed shape, as occurs for the inducing patterns (and somewhat for the Z-aligned case).

**Discussion**

Dependence on local cues for shape discrimination raises the question, “For which local pacman cues would subjects look?” We analyze each possibility in turn:

a. They could look, for discrimination, at the close-to-center pacman which are open-mouthed for parallelograms and close-mouthed for triangles (see Figure 1). However, in this case, all detection FAs should be reported as triangles, since with rotated pacman, those that are close-to-the-center are always close-mouthed (see Figure 11A, top and Figure 1C). In fact, as Figure 11B illustrates, with NON-aligned and Z-aligned patterns, the shape reported was about half-half triangles and parallelograms (54% and 53% triangles, respectively); for T-aligned and P-aligned patterns, there are indeed more triangle reports (65% and 75%, respectively), but this difference would remain difficult to explain, if subjects were using the local cue as determinant of shape. The fact that Z-aligned is reported more as parallelogram than is T-aligned and P-aligned would again support the conclusion that it is the complete figure, not the local cue that is used, since only the Z-aligned case has a hint in this direction.

b. Subjects could use the orientation of the pacmen that are far from the fixation point to guess figure shape. In fact there is a tendency to report a parallelogram shape when both far pacmen face inward (for triangle-inducing pacman, especially for group III, leading to significantly more correct triangle reports for OUT trials than for IN trials (Figure 10). However, this effect was seen only for group III and even for this group only in the case where their detection was accurate. We therefore reject this local cue as being the generally overriding determinant factor for shape discrimination.

We must conclude that there is no evidence to support a claim that local features are used to discriminate induced figure shape.

**Summary**

Testing subjects on simultaneous detection of illusory contour figures and discrimination of their shape, we found that both detection and discrimination increase as a function of the time before presentation of a masking stimulus (SOA). The critical processing time for significantly better-than-chance detection or discrimination was ~100 ms, similar to that reported in earlier studies (Reynolds, 1981; Ringach & Shapley, 1996). Signal detection theory analysis suggests that the increased rate of detection hits is not accompanied by an increased rate of false alarms (Figure 2B), so that it is a true increase in detectability and discriminability, not just a shift in criterion.

Nevertheless, there were significant differences between detection and discrimination suggesting that these are two separate processes. We found a significant number of cases of detection without discrimination. Interestingly, there were also cases where discrimination was accurate, even without detection. That is, we found that subjects report with a better than chance probability the shape of an illusory contour figure, even without conscious experience of having detected the figure. This finding suggests that implicit processing affects discrimination judgment, even without explicit, reportable perception. Implicit perception of illusory contours has been studied before only in patient subjects who were deprived of the explicit experience of seeing illusory contour figures, as also real figures, but responded above chance to indirect measurements.
of perception (e.g., neglect patients: Vuilleumier & Landis 1998; Vuilleumier, Valenza, & Landis, 2001; blindsight: Marcel, 1998; see also Cowey & Stoerig, 1991; Weiskrantz, 1990).

On the other hand, this implicit “knowledge” concerning the figure’s shape is different than that which results from the conscious experience of having detected the figure: First of all, shape discrimination performance is superior when it is accompanied by conscious detection (90% vs. 70% for SOA > 150 ms). In addition, and most importantly, only when detection is conscious is shape discrimination also able to make use of additional local features, such as the orientation of the fourth pacman in the case of an illusory triangle. This is consistent with the conclusions of Reverse Hierarchy Theory (RHT; Ahissar & Hochstein, 1997, 2004; Hochstein & Ahissar, 2002) that local details (represented at low cortical levels) are learned and integrated into conscious perception only after a general “gist of the scene” (as represented at high cortical levels) is consciously perceived (Treisman, 2006; Koch & Tsuchiya 2007). Thus, while of course the orientation and relative orientations of the pacmen do influence in a general way the conscious detection of a figure and discrimination of its shape, nevertheless, the orientations themselves and in particular the specific orientation of the “extra” pacman only influence shape discrimination when there has been prior conscious figure detection. In terms of RHT, only then does perception return to lower cortical levels to integrate detailed information available there. This finding that the orientation of the “extra” pacman is not used as a cue to figure shape when the figure is not explicitly detected and the finding that orientation of the closer pacmen is also not used for figure discrimination (as evidenced by subjects’ not always guessing a triangle shape for rotated pacmen stimuli; see Results) support the conclusion that subjects really are looking for the illusory figure when they decide whether to answer “yes” for detection, and that they base their discrimination on the shape of the illusory figure rather than on local features.

**Three performance patterns**

A closer look at the results on a per subject basis revealed that there are three performance patterns. We based the division into groups on subjects’ individual relative differences between discrimination and detection asymptotic performances and then found that the groups had different detection and discrimination performance as a function of SOA or processing time. Superior performance for detection over discrimination was found in group III. Group II were better than group III in discrimination, leading to a switch over, with longer SOAs, from better detection to better discrimination. Finally, group I was better than group II in detection, resulting in nearly identical detection and discrimination rates at all SOAs.

Having defined the groups on this basis, we also found other differences in their performance characteristics, upon further analysis of their separate results. Thus, the groups differ in their rates of discrimination without detection, a phenomenon we relate to “blindsight” (Cowey & Stoerig, 1991; Marcel 1998; Weiskrantz, 1990). In addition, the groups differ in their use of local features for both detection and discrimination: group III makes the most use of the orientation of the fourth pacman as a cue for the presence and shape of the illusory figure, with this local feature having more effect on discrimination than on detection. These comparisons demand that we speculate as to the source of the differences among the three performance groups. An obvious hypothesis for the mechanism underlying these different patterns of performance in the dual detection–discrimination task is that the different groups of subjects may use different strategies for task performance. These strategies may be based on the way they analyze incoming cues and evaluate the information available in the received feedback. Different strategies should be manifest in different decision criteria but not in amount of information perceived, i.e., in d’ detectability level. For example, different subjects could report having experienced an illusory figure on the basis of weaker or stronger cues and lower or higher confidence levels. Indeed, the detection performances at long SOA (>100 ms) for groups II and III are very similar (Figure 6B), with their criteria being somewhat different (group III are more conservative; Figure 7). This could be due to a difference in strategy of the two groups. However, the discrimination performance for these same groups have very different d’ values (together with different criteria)—suggesting a difference in information received, not just in strategy of its use. Comparing performance for groups I and II, there are large differences in d’ for both detection and discrimination—without differences in criteria (Figure 7). In summary, it would seem that there are differences between the groups that depend on their perceptual abilities, not only on their strategies for its use. In addition, the positive feedback given to the subjects should lead them to use of common strategies.

Comparison of the different performances together with the finding that the differences among the groups were in detectability level and not mainly in criterion allows us to speculate instead that group I are the “experts,” group III are the most naive (leading ultimately to being affected by local features), and group II are at an intermediate level of experience in perceiving illusory figures. Further study is required to determine if there is a transition from one group level to another with training.

**Two processes**

As mentioned above, performance varies with SOA, but in a manner that is different for different subject groups. The very fact that detection and discrimination vary
detecting a salient region

How do the three groups perform these separate detection and discrimination tasks? Inspired by Stanley and Rubin (2003), we suggest that detection is above-threshold perception of a salient region forming a surface (where the term salient refers to the region’s differentiation from other regions, and the term surface implies that all the points in this region belong to a single contiguous area, which may be separated in depth from neighboring regions).

All subjects had more FAs, i.e., more reports of detection, for Z-aligned than for other aligned rotated pacman patterns (Figure 11). This might be due to the approximately defined salient region formed by the far pacman plus the constraining presence of the near pacman (though the latter are in the wrong direction and half of the time have the wrong opening angle). This significantly greater FA rate supports the conclusion that subjects are looking for a salient region.

In group III (naïve) subjects, the attempt to achieve best detectability, that is, to pull the signal out of its noise and reach threshold, is realized by summation of separate cortical representations of this salient region for a triangle and for a parallelogram. Consequently, when they have perceived a salient region, they use its approximate location (rather than shape) at long SOAs to return to lower cortical levels, find the pacman, and use them directly to determine the shape of the figure. Thus, they are very influenced by the IN vs. OUT orientation of the fourth pacman.

Group II subjects are better able to compare activations in the two representations and determine the shape of the figure. Even without increased detectability, learning to perform this comparison improves discrimination, which becomes better than detection. That is, even if detection is below threshold, discrimination—a forced choice response—may be better than chance. The subliminal high-level signal may be sufficient to determine the figure’s shape. In this case, subjects are unaware of the presence of the illusory figure but do significantly better than chance on guessing its shape.

Finally, detection and discrimination for (expert) group I appear similar, presumably because these subjects use the separate triangle and parallelogram representations to determine both detection and discrimination. They have very few errors at long SOAs—1–2 errors per subject per SOA—so that these may derive simply from response error. The somewhat greater frequency of detection without correct discrimination than the reverse may be a result of our using a fixed order of response, i.e., detection first and discrimination second.

Illusory figures and object perception

Grill-Spector and Kanwisher (2005) found that as soon as subjects detected an object, they also knew its category, but not its identity. Is our discrimination task equivalent to their “categorization” or to their “identification?” For group III, illusory shape discrimination may be like subordinate identification rather than categorization, leading to superior performance for detection than for discrimination (compare our Figure 6A, group III and their Figure 2 detection vs. identification). On the other hand, for group I, detection is extremely easy, and subjects are sufficiently confident that as soon as they can discriminate an illusory shape, they also know that it is there (compare our Figure 6A, group I with their Figure 2 detection vs. categorization).

For intermediate group II, the situation is more complex: At short SOAs, performance is like that of group III,
but at long SOAs discrimination becomes easier than detection. It is generally accepted that with increasing experience, subordinate level identification becomes like basic level categorization (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Tanaka, 2001). Thus, for these subjects discrimination becomes easier and should be equivalent to detection. In fact, we found instances where group II subjects reliably report the shape of a Kanizsa figure, even when they claim they have not detected the figure itself, a result not found by Grill-Spector and Kanwisher (2005). This may be because they used a 2-AFC paradigm, while our subjects needed to set a subjective threshold. Thus, even if the same analyzers are used for detection and discrimination, in our case the two computations may be different (see Graham, 1989). Presumably, with a 2-AFC paradigm the same computation would be used for detection and categorization.

Conclusions

We conclude that illusory figure detection and shape discrimination are separate tasks, and some subjects achieve one without the other—in either direction. Performance on the detection task in our case was a measure of the explicit experience of seeing the illusion. In agreement with the conclusions of Stanley and Rubin (2003), detection of a Kanizsa figure may depend first and foremost on perception of a salient region. The way this region is used for figure shape discrimination depends on experience with this type of illusory figure. Thus, figure detection may depend on a multitude of properties, which vary variable times, so that sometimes there is enough "perceptual evidence for a positive answer to the detection question but not enough for shape determination, while in other cases there may be sufficient "perceptual evidence" to guess the shape even without having the sense that there actually was a figure there at all.

As an example of the difference between the detection and the discrimination tasks, orientation of the extra pacman—the fourth pacman not acting as an inducer for a triangle shape—has different effects on detection and discrimination: When it points OUT, it makes detection more difficult (contributes to reporting no figure in inducing trials) and discrimination easier (reporting a triangle). On the other hand, when the pacman points IN, detection is easier, and discrimination more difficult.

The finding that the orientation of the fourth pacman only influences discrimination when there is conscious detection of a figure is consistent with the prediction of Reverse Hierarchy Theory (Hochstein & Ahissar, 2002) that perception begins with a general gist of the scene and later includes local details. Only after perceiving the figural salient region gist, can perception return to detailed information at lower cortical levels.

References


