Unconscious priming by illusory figures: The role of the salient region

Tommaso Poscoliero
Department of Neurological, Neuropsychological, Morphological, and Motor Sciences, University of Verona, Verona, Italy

Carlo Alberto Marzi
Department of Neurological, Neuropsychological, Morphological, and Motor Sciences, University of Verona, Verona, Italy
Istituto Nazionale di Neuroscienze (National Institute of Neuroscience, Turin, Italy)

Massimo Girelli
Department of Neurological, Neuropsychological, Morphological, and Motor Sciences, University of Verona, Verona, Italy
Istituto Nazionale di Neuroscienze (National Institute of Neuroscience, Turin, Italy)

In this study we provide evidence that unconscious priming can be obtained as a result of the processing of the salient region (SR) of illusory figures and without that of illusory contours (ICs). We used a metacontrast masking paradigm where illusory figures were masked by real figures. In Experiment 1 we found a clear priming effect when participants were asked to discriminate between square and diamond masks preceded by congruent or incongruent illusory square or diamond primes. It is likely that metacontrast impairs the processing of ICs but not of the SR; therefore the above result strongly suggests that the priming effect was specifically related to the processing of the SR. In Experiment 2 participants were tested in the same task as in Experiment 1 with additional primes in which the inducers were presented in the same locations but their shapes were changed so as to modify the global configuration. We termed these primes High, Low, and No Salient Region (HSR, LSR, and NSR, respectively). The HSR condition replicated Experiment 1, whereas in the LSR and NSR conditions the priming effect got progressively smaller. The results of Experiment 1 were replicated with the priming effect significantly larger in the HSR than in all other conditions. It was also larger in the HSR than in LSR condition and smallest but still present in the NSR condition. Taken together, these results indicate that the unconscious processing of only the SR yields a priming effect and that a reduction of the saliency of the SR leads to a reduction of the priming effect, while its elimination does not abolish it.

Introduction

One of the most important functions of the human visual system is the construction of perceptually coherent surfaces and objects through the synthesis and the integration of physical inputs from the environment. This function plays a fundamental role in nature allowing predators to counteract camouflage, that is, the ability to minimize the number of visual cues that distinguish an object from the background (Nieder, 2002). It is now common knowledge that visual illusions are a useful tool to understand how the visual system deals with the perception of surfaces and objects. In particular, Kanizsa's illusory figure (Kanizsa, 1987) has been widely used both in psychophysical and neurophysiological studies for this purpose (for reviews see Spillmann & Dresp, 1995; Seghier & Vuilleumier, 2006).

Kanizsa (1987, p. 40) described three main properties of illusory figures in the following sentences:

(I) In a particular region of the visual field, transformations of brightness and/or mode-of-ap-

Citation: Poscoliero, T., Marzi, C. A., & Girelli, M. (2013). Unconscious priming by illusory figures: The role of the salient region. *Journal of Vision*, *13*(5):27, 1–12, http://www.journalofvision.org/content/13/5/12, doi:10.1167/13.5.27.

doi: 10.1167/13.5.27 Received August 17, 2012; published April 26, 2013 ISSN 1534-7362 © 2013 ARVO

pearance occur that phenomenally distinguish that regions, even though stimulations from all regions is the same. (II) Phenomenally, the region undergoes a displacement in the third dimension, and is seen as situated in front of or over the rest of the field. (III) The region possesses a more or less clear margin, which separates it from the contiguous areas, and also crosses regions where there is no quantitative or qualitative change in the stimulation. [. . .]

The term *region*, with which Kanizsa identifies a portion of the visual field characterized by specific perceptual features (illusory contours, brightness enhancement, and depth stratification), was recently used by Stanley and Rubin (2003, 2005) with the name "salient region" (SR), a term borrowed from computer vision science. In this field of research, SR indicates a set of contiguous image pixels that are likely to correspond to a major surface in a scene and that are easily detected, in terms of computational power, by algorithms developed to detect specific areas of interest. The logic underlying this approach is to identify a surface from its saliency, overcoming the problem of the high computational cost of detecting surfaces from their contours (e.g., Marr, 1982). While, by topological necessity, a region is always bounded by contours, an SR is an approximate region without detailed contours but still detectable by means of an algorithm. In the human visual perception framework, Stanley and Rubin (2003, 2005) used the term salient region to indicate an enclosed region of the visual field that creates a first impression of a global surface, even though, upon closer scrutiny, this surface and the corresponding contours are not perceptually or physically present. A similar condition occurs in the case of form-from-motion phenomena where a group of single dots moving coherently on a background of randomly moving dots assumes the status of a surface (Spillmann, 2009). In this context, Kanizsa's illusory figure could be considered as an SR characterized in addition by illusory contours, brightness enhancement, and depth stratification, that is, the perceptual properties described by Kanizsa (1987).

In order to elucidate the temporal evolution through which illusory figures, and particularly their illusory contours, are generated by the human visual system many studies have dealt with the so-called "microgenesis" of Kanizsa's figure using a backward masking paradigm (Gellatly, 1980; Reynolds, 1981; Ringach & Shapley, 1996; Imber, Shapley, & Rubin, 2005; Barlasov-Ioffe & Hochstein, 2008). Starting from the assumption that the perception of the shape of the illusory figure is closely related to the perception of the illusory contours, in these studies participants were instructed to discriminate the shape of the illusory figure when it was not completely perceived, or totally unperceived, as a result of backward masking. In this regard, Reynolds (1981) argued that the duration of presentation of an illusory figure required for the perception of illusory contours, before masking, should be greater than 100 ms. This duration was confirmed by Ringach and Shapley (1996) who found that the time required to identify the shape of an illusory figure was 117 ms. Therefore, on the basis of these data it is possible to conclude that roughly within the first 100 ms there is no access to conscious perception of the illusory contours.

An interesting issue concerns the influence (i.e., priming effect) that the unconsciously processed shape of a Kanizsa's figure can exert on the perception of a real masking figure. To our knowledge, no study has addressed this problem. Only one study (Barlasov-Ioffe & Hochstein, 2009), using a prime-matching paradigm, evaluated whether a sequentially created illusory figure could facilitate a participant's performance in a subsequent same-different shape-discrimination task. In this study the illusory figure was rendered invisible by using an extension of the method proposed by Rock and Linnet (1993) in which the inducers (Pac-Men) that constitute the illusory figure were presented separately and sequentially, either in screen or in retinal coordinates, with the result that participants were not able to perceive the illusory figure. Despite that, the illusory figure facilitated performance in the matching task in the retinal-coordinates condition. Barlasov-Ioffe and Hochstein (2009) proposed that the priming effect does not depend on the processing of the illusory contours but solely on the SR. In accord with this possibility Stanley and Rubin (2003, 2005), proposed that the SR and the illusory contours are independently processed by the visual system: The former at high cortical level by the lateral occipital complex (LOC) and the latter by early visual areas V1 and V2 by means of feedback projections reentering from LOC. This interpretation is in agreement with Mendola, Dale, Fischl, Liu, and Tootell (1999) who found differential processing of illusory contours and coherent shapes within LOC. Also Murray et al. (2002), on the basis of the latency of visual evoked potentials, proposed a model supporting the idea of an initial processing of the SR by LOC, followed by a subsequent processing of the illusory contours carried out by V1 and V2 via feedback projections (see also Grill-Spector & Kanwisher, 2001). Barlasov-Ioffe and Hochstein's (2008) hypothesis that the SR is the crucial element yielding the priming effect is also in keeping with Bar and Biederman's (1999) findings, indicating the human homologue of macaque V4 visual area, which is very close to LOC, as the neural locus of subliminal priming.

In the light of the above hypotheses, the aim of the present study was to provide evidence, by means of a backward masking paradigm, of the influence (i.e., priming effect) that an unconsciously processed illusory figure exerts on the recognition of a real masking figure. In particular, we tested the hypothesis that this priming effect could be obtained by processing only the SR rather than the illusory contours. By using an appropriate timing, that is, with an stimulus onset asynchrony (SOA) between the onset of the inducers of the illusory figure and that of the mask figure below 100 ms (Reynolds, 1981; Ringach & Shapley, 1996) it is possible to mask the shape of the illusory figure, thereby eliminating the conscious perception of illusory contours and leaving presumably only the SR. It is well established that the perception of the shape of an illusory figure is necessary for perceiving the contours. Since illusory contours do not have a physical counterpart, the failure to perceive them necessarily implies a complete lack of processing, even unconsciously. However, an unconscious processing of the shape of the illusory figure, based on the SR, should remain available and behaviorally measurable. In conclusion, the failure to perceive the shape of an illusory figure implies the lack of processing of the illusory contours but does not preclude the possibility that its shape could be unconsciously discriminated on the basis of the SR. As previously mentioned, in fact, Kanizsa's figure represents an SR, that is, a perceptually enclosed region of the visual field characterized by a shape according to the Gestalt law of closure. With an appropriate timing allowing masking of the shape of the illusory figure a priming effect should not depend on the illusory contours but instead on an unconscious processing of the shape of the SR. Therefore, even if the shape of the SR is not visible, it might facilitate the discrimination of the masking figure. This would be consistent with the direct parameter specification theory (DPST) (Neumann & Klotz, 1994; Klotz & Wolff, 1995; Ansorge, Klotz, & Neumann, 1998), which states that the suppression of the awareness of stimulus attributes, such as shape, as a result of visual masking does not delete the information contained in the stimulus that remains available to the visual system.

In the present study, a particular kind of backward masking, i.e., metacontrast, was used (Breitmeyer & Ogmen, 2000): This procedure was suggested by the evidence that metacontrast inhibits the activity of feedback projections between higher and lower visual areas (for a review, see Breitmeyer, 2007) involved in the processing of illusory contours but does not interfere with the processing of the SR.

Experiment 1

According to the DPST (Neumann & Klotz, 1994; Klotz & Wolff, 1995; Ansorge et al., 1998), the unconsciously processed shape of a stimulus could prime the discrimination of the shape of the incoming mask. Specifically, the discrimination of the shape of the mask should be faster when prime and mask have the same shape (congruent condition) than when they have a different shape (incongruent condition). The aim of Experiment 1 was to extend the DPST to the SR of the Kanizsa's illusory figure. The rationale was the following: If the unconsciously processed shape (square vs. diamond) of the SR constituting the Kanizsa's illusory figure primes the discrimination of the shape (square vs. diamond) of the real figure (mask), then the discrimination of the latter should be faster in the congruent than in the incongruent condition. This facilitation, defined as *unconscious priming effect*, can be demonstrated by the difference between mean choice reaction time (CRT) in incongruent (e.g., square - diamond) and congruent (e.g., square - square) trials, and it is measured using a modified version of the unconscious priming paradigm used by Breitmeyer, Ogmen, Ramon, and Chen (2005). Moreover, in order to assure that the shape of the illusory priming figure is masked at the optimal SOA (65 ms), we determined its visibility by using a two-alternative forced choice task. Thus the experiment consisted of two tasks, one aimed at measuring the unconscious priming effect and the other at measuring the visibility of the prime in order to rule out the discrimination of the illusory contours.

Methods

Participants

Ten (six females) healthy paid volunteers, aged 21–40 (mean = 25.3), took part in the experiment. All were right handed and had normal or corrected-to-normal vision. All participants provided informed consent and the study was carried out in accordance with the Declaration of Helsinki.

Stimuli

The stimuli were displayed at a 75-Hz frame rate on a 19-in cathode ray tube monitor (Model: LG 901b) with a desktop size of 1280 × 1024 pixels. Contrast and brightness were adjusted at 100% and 0%, respectively. The stimuli were presented on a uniform white background with a luminance of 90 cd/m^2. E-Prime software version 1.1 was employed to control stimulus presentation and to record participants' responses. All stimuli were built in Adobe Photoshop CS3 as bitmaps.

The prime stimulus was an illusory Kanizsa square or diamond in a modified version proposed by Varin (1971) (see Figure 1). Each stimulus was composed of four inducers, each of which composed of five concentric black circular sectors of 270°. Each sector

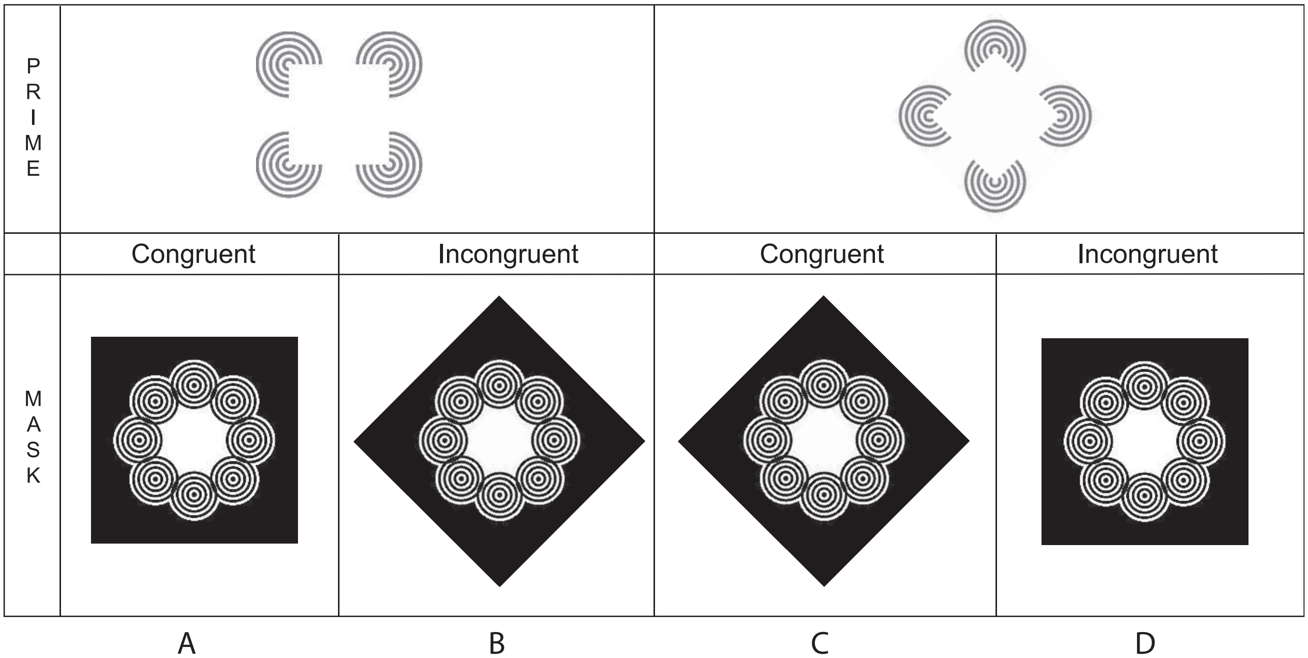

Figure 1. Representation of prime and mask stimuli in Experiment 1. Prime stimuli (top row) consisted of an illusory Kanizsa square (A, B) and diamond (C, D). Mask stimuli (bottom row) consisted of a real square (A, D) and diamond (B, C). A and C columns represent congruent conditions (prime and mask with the same shape), B and D columns represent incongruent conditions (prime and mask with different shape). For details of target and mask configuration see the description of stimuli in the Methods section.

subtended a visual angle of: 1°, 0.8°, 0.6°, 0.4°, and 0.2°, respectively. Circular sectors' thickness was 0.05° of visual angle. The total length of the square or diamond illusory contour was 1.5° of visual angle, and the eccentricity of each inducer from the center of the illusory square was 1.1°. The support ratio, defined by Lesher and Mingolla (1993) as the ratio of the length of the real side made of the endings of the circular sectors, relative to the total length of the illusory side, was 0.16. Luminance of each circular sector was of 12 cd/m^2 yielding a contrast with the white background of 0.76.

The mask stimulus was designed according to the fundamental feature of the metacontrast technique, which requires that the mask does not spatially overlap with the prime (for a thorough review, see Breitmeyer & Ogmen, 2000). As shown in Figure 1, the mask stimulus could be a square or a diamond with a real contour of 4° of visual angle with eight circular elements each of which, in turn, were composed of four black concentric circles, symmetrically placed around the center. The area between the outermost circles and the side of the mask was filled with solid black. The luminance of the mask was of 0.3 cd/m^2 yielding a contrast with the white background of 0.99. Circles subtended a visual angle from highest to lowest of: 0.9°, –0.7°, –0.5°, and –0.3°, and their thickness was 0.05°. The four circles appeared in the portion of the white background corresponding to the gap between the concentric circular sectors of the prime stimulus as required by metacontrast technique.

Procedure and task

Each participant was tested in two experimental sessions in successive days. In the first session participants were tested on a mask-choice reaction time (RT) task in order to measure the priming effect and in the second session they were tested on whether they were able to detect the shape of the prime stimulus. Participants were seated in front of a PC monitor at a distance of 57 cm in a dimly lit room and were completely unaware of the purpose of the experiment. As shown in Figure 2, a trial consisted of a fixation period of 500 ms followed by an acoustic warning stimulus (duration 200 ms; frequency 1000 Hz); after a random interval of 500–700 ms the prime (duration 26 ms) was presented and after an inter-stimulus interval of 39 ms was followed by the mask (duration 26 ms), leading to a prime-mask SOA of 65 ms. An additional fixation period of 1000 ms concluded the trial leading to an inter-trial interval of 1500 ms. In each trial, prime and mask were lateralized to the same visual field with randomized presentation either to the left (LVF) or to the right visual field (RVF) at an eccentricity of 4.5° of visual angle from the center of the stimulus to the fixation cross (0.3° of visual angle). A lateralized stimulus presentation was chosen in order to test for possible hemispheric effects. Half of the prime-mask pairs could be congruent in shape and half incongruent. The combination of congruency and visual field was randomized.

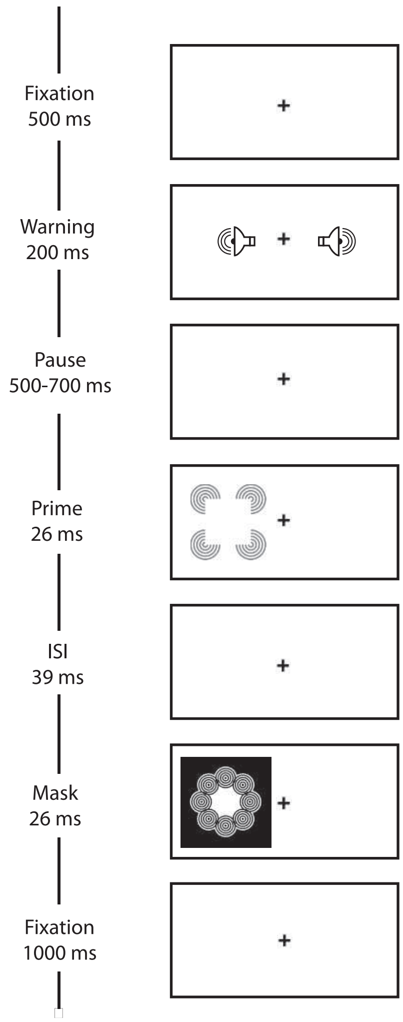

Figure 2. Experiment 1. Example of a congruent trial in the left visual field with a square shape of prime and mask.

The mask-choice RTs session included six blocks, which, in turn, included 80 randomly presented trials divided into 40 congruent trials (20 in the RVF and 20 in the LVF) and 40 incongruent trials (20 in the RVF and 20 in the LVF). Thus the experimental design was a 2 × 2 within-subjects design with Congruency and Visual Field as main factors. Participants were instructed to keep the gaze on the fixation cross at the center of the screen throughout the session and to discriminate as quickly and accurately as possible the shape of the mask by pressing one of two response keys with the index or the middle fingers of their right hand. Half of the participants pressed "B" for the square and "N" for the diamond and vice-versa for the other half of the participants. After the first three blocks, participants were allowed a brief rest. A low cutoff of accepted RTs was set at 140 ms without a high cutoff (see Ulrich & Miller, 1994). Participants who did not comply with this limit in more than 5% of the total trials were not considered for statistical analysis. No participants exceeded these limits. It is worth pointing out that participants were not informed of the presence of the prime stimulus. At the end of the session participants were asked a series of questions to assess whether they had perceived the prime (see Kentridge, Nijboer, & Heywood, 2008). In addition, in order to have an objective measure of the visibility of the shape of the prime, the following day participants were tested in a prime shape visibility session. Stimuli were the same as in the mask-choice task. After a demonstration of the sequence of events in a slow version, aimed to show the prime stimuli, participants were instructed to discriminate as accurately as possible the shape of the prime stimuli and to respond by using the same target-response combination as in the mask-choice task.

Results and discussion

As to the mask-choice task, a two-way repeated measures analysis of variance (ANOVA) on correct RTs was carried out with Congruency (congruent vs. incongruent) and Visual Field (right vs. left) as main factors. The effect of Visual Field was not significant, $F(1, 9) = 0.13$, $p = 0.729$, while that of Congruency was highly significant, $F(1, 9) = 132.91$, $p < 0.001$, partial eta squared = 0.937, indicating, as expected, that participants were faster at recognizing the mask's shape in the congruent (443 ± 64 ms) than in the incongruent condition (497 ± 62 ms) (Figure 3) yielding a priming effect of 54 ms. The interaction between Congruency and Visual Field was not significant, $F(1, 9) = 0.65$, $p = 0.439$. Accuracy was not analyzed because participants' performance was at ceiling (above 90% in all conditions). At the end of the experiment each participant was asked to give a full description of the display: Eight participants occasionally reported flickering prior to the onset of the mask, but no participant reported the

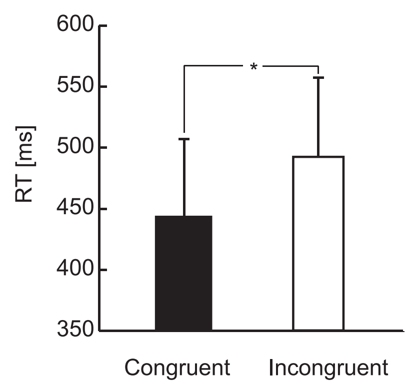

Figure 3. Experiment 1. Mean choice RTs and standard deviation relative to the discrimination of the mask shape in congruent and incongruent conditions. Asterisk indicates significant differences at $p < 0.001$.

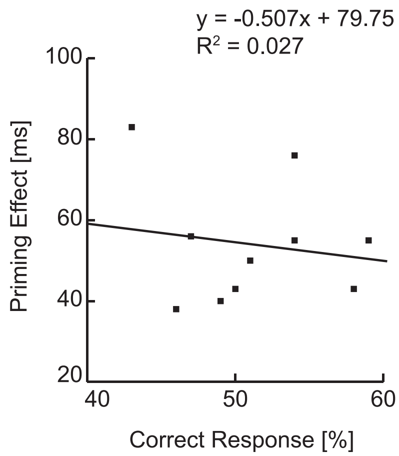

Figure 4. Experiment 1. Scatter plot and the best-fitting linear relationship between the 10 pairs of correct response percentages in prime shape visibility task and the priming effect in mask choice RTs task.

presence of the prime. They were then shown the prime stimuli on the display monitor and were asked whether they had seen them prior to the mask stimuli. None of them reported their presence.

As to the prime-shape visibility task, accuracy was compared to 50% chance in one sample *t* test. The mean accuracy of all conditions (50.92%) was not different from chance, $t(1, 9) = 0.67$, $p = 0.518$, providing an objective measure that the shape of the prime was not perceived in agreement with the participants' subjective reports. In order to further support this conclusion, another statistical analysis was carried out. Following Breitmeyer et al.'s (2005) reasoning, one could argue that if, for some or all observers, there were a few trials during which the prime-stimulus shape was seen, then these trials might have contributed to the priming effect. If this was the case a positive correlation between a participant's priming effect and the percentage of correct responses in the prime visibility task should be found. A correlation test for 10 participants' pairs of correct response percentage and the corresponding priming effects, as measured by choice RT, showed no significant effect, Pearson $r = -0.16$, $p = 0.633$ (Figure 4).

These results demonstrate, in keeping with the DPST, that the unconscious processing of the shape of the SR yields a priming effect. Even without the processing of the illusory contours a priming effect takes place when the SR has the same shape as the subsequent mask.

Experiment 2

Experiment 1 demonstrated that the priming effect could be produced by the SR alone without the need to process the illusory contours. One could argue that the priming effect is not due to the shape of the SR as an enclosed region of the visual field but to the position of the inducers at the four corners of a square or a diamond. If so, a priming effect should be found even when the four inducers are arranged not to form an SR. It is also possible that the two factors (SR and position of the inducers) are not mutually exclusive but that both contribute to produce the priming effect. Moreover, if the SR does play a central role in producing the priming effect, a modulation of its saliency, in terms of brightness enhancement and depth stratification, should modulate the priming effect. Even if at an appropriate SOA of 65 ms illusory contours are not processed most likely due to the inhibition of feedback projections as a result of metacontrast masking, it is possible that some information relative to brightness enhancement and depth stratification still survives and contributes to modulate the saliency of the SR and consequently the strength of the priming effect (to this point see also Mendola et al., 1999).

In the light of the above considerations, the rationale of Experiment 2 was the following: If the SR, rather than the position of the inducers, plays a central role in yielding the priming effect, a modulation of its saliency should lead to a modulation of the strength of the priming effect while its absence should eliminate or strongly reduce priming.

Methods

Participants

A new group of 20 (13 females) healthy paid volunteers, aged 20–36 (mean = 24.2), took part in the experiment. All were right handed and had normal or corrected-to-normal vision. All participants provided informed consent and the study was carried out in accordance with the Declaration of Helsinki.

Stimuli

The prime stimuli could be of four different types, as shown in Figure 5, that we termed as follows: High Salient Region Stimuli (HSR) were the same as in Experiment 1; Low Salient Region Stimuli (LSR) were composed of four inducers, each of which composed of five concentric black circular sectors of 90°, complementary to the inducers of the High Salient Region Stimuli. According to De Weert and Kruysbergen (1987), in this way, the four inducers produced an *assimilation effect*, rather than a contrast effect as in the case of HSR, that generated an illusory square (or diamond) whose area appeared darker than the background (see also De Weert et al., 1995). Therefore this condition was defined as LSR. Moreover, from a

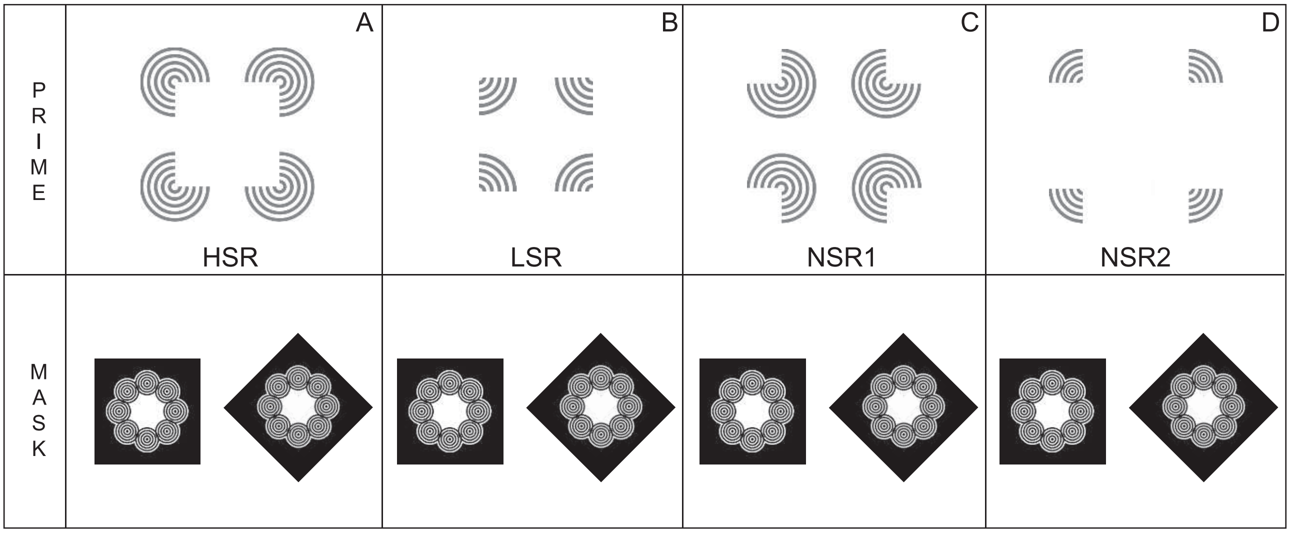

Figure 5. Experiment 2. Representation of square prime and mask stimuli: Prime stimuli (top row) in the four types: A-HSR (High Salient Region); B-LSR (Low Salient Region); C-NSR1 (No Salient Region 1); D-NSR2 (No Salient Region 2). Mask stimuli (bottom row): left hand side congruent condition; right hand side incongruent conditions.

perceptual point of view, this alternative illusory figure does not appear as a uniform surface lying in a plane close to the observer but as a nonuniform, partially textured surface without index of depth stratification. The visual angle of illusory contours was the same as that of High Salient Region Stimuli (1.5°). No Salient Region Stimuli (NSR1) and (NSR2) were composed by the four inducers of the High and Low Salient Regions Stimuli, respectively, rotated by 180°. NSR1 and NSR2 stimuli represented the controls for the first two stimuli in that they prevented the formation of the illusory figure and, consequently, also of the SR. Each of these four types of stimuli was presented as a square or a diamond shape. Mask stimuli, luminance, eccentricity, and timing were the same as in Experiment 1.

Procedure and task

As in Experiment 1, participants were tested in two experimental sessions in successive days. In the first session they performed a mask-choice RTs task. This session included four blocks of 192 trials, in each of which the prime stimulus was one of the four types described above. Each block was divided in 96 congruent trials (48 in the RVF and 48 in the LVF) and 96 incongruent trials (48 in the RVF and 48 in the LVF). Each block was divided in three sub-blocks of 64 trials to allow participants to take brief pauses as needed. Block order was counterbalanced across participants. A $2 \times 2 \times 4$ within-subjects ANOVA was carried out with Congruency, Visual Field, and Prime Stimulus Type as main factors. Task and questions about the visibility of the prime shape were the same as in Experiment 1.

After preliminary viewing of the sequence of events in a slow version aimed to show the prime stimuli, participants performed a prime-shape visibility task in the second day of testing. This session included the same number of trials as the first session divided in four blocks of 192 trials in which the type of prime stimulus was the same. Each block included 96 congruent trials (48 in the right visual field and 48 in the left visual field) and 96 incongruent trials (48 in the right visual field and 48 in the left visual field). Also in this case each block was divided in three sub-blocks of 64 trials to allow rest as needed. Blocks order was counterbalanced across participants using the same sequence of Session 1. At the beginning of each block participants were shown the type of stimuli that they were to discriminate (square vs. diamond) as accurately as possible.

Results and discussion

For the mask-choice task, a three-way repeated measures ANOVA on correct RTs was carried out with Congruency (congruent vs. incongruent), Visual Field (right vs. left), and Prime Stimulus Type (HSR vs. LSR vs. NSR1 vs. NSR2) as main factors. The effect of Congruency was significant, $F(1, 19) = 72.65$, $p < 0.001$, partial eta squared = 0.793, indicating, as in Experiment 1, that participants were faster in recognizing the mask's shape in the congruent (454 ± 74 ms) than in the incongruent condition (482 ± 68 ms) yielding a priming effect of 28 ms. The main effects of Visual Field were not significant, $F(1, 19) = 2.67$, $p = 0.119$, and the same was true for Prime Stimulus Type, $F(3, 57) = 0.48$, $p = 0.698$.The interaction between Congruency and Prime Stimulus Type was significant,

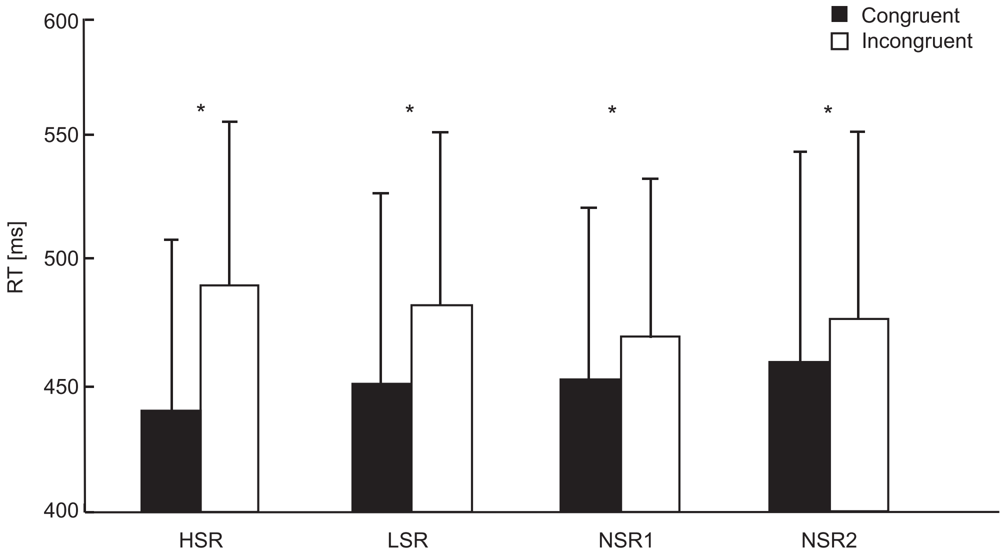

Figure 6. Experiment 2. Mean choice RTs and standard deviations relative to the discrimination of the mask shape in congruent and incongruent conditions as a function of prime stimulus type. HSR (High Salient Region); LSR (Low Salient Region); NSR1 (No Salient Region 1); NSR2 (No Salient Region 2). Asterisks indicate significant differences at $0.0001 \leq p \leq 0.001$.

$F(3, 57) = 22.18$, $p < 0.001$, partial eta squared = 0.539, indicating that the priming effect was different for the different stimulus types. All the other interactions were not significant. For each stimulus type, a post hoc paired-sample *t* test of the Congruency main effect was carried out showing significant differences for all stimulus type conditions, $3.98 \leq |t_{19}| \leq 9.64$; $0.0001 \leq p \leq 0.001$ (Figure 6).

A further series of post hoc paired-sample *t* tests, using the Holm-Bonferroni correction, on the priming effect among the four different prime stimulus types was carried out. The results, shown in Figure 7, were as follows:

High Salient Region (46.70 ± 21.84 ms) was significantly different from Low Salient Region (32.62 ± 21.07 ms), $|t_{19}| = 2.77$, $p = 0.012$, No Salient Region 1 (15.77 ± 14.85 ms), $|t_{19}| = 7.36$, $p < 0.001$, and No Salient Region 2 (15.51 ± 17.46 ms), $|t_{19}| = 8.50$, $p < 0.001$.

Low Salient Region (32.62 ± 21.07 ms) was significantly different from No Salient Region 1 (15.77 ± 14.85 ms), $|t_{19}| = 2.99$, $p = 0.007$, and No Salient Region 2 (15.51 ± 17.46 ms), $|t_{19}| = 4.23$, $p < 0.001$.

No Salient Region 1 (15.77 ± 14.85 ms) and No Salient Region 2 (15.51 ± 17.46 ms) were not significantly different from each other, $|t_{19}| = 0.06$, $p = 0.951$.

By subtracting the priming effect in the NSR1 and NSR2 conditions from HSR and LSR conditions, respectively, it is possible to evaluate the modulation of the priming effect produced by the new types of primes adopted in this experiment. The difference between HSR and NSR1 (31 ± 18.8 ms) was significantly different from the difference between LSR and NSR1 (17 ± 18.1 ms), $|t_{19}| = 2.47$, $p < 0.023$. Moreover, in order to normalize this modulation, for each subject, the two differences were calculated as:

$$\frac{[RT(HSR) - RT(NSR1)]}{½} \times [RT(HSR) + RT(NSR1)].$$

$$\frac{[RT(HSR) - RT(NSR2)]}{½} \times [RT(HSR) + RT(NSR2)]. \quad (1)$$

The normalized difference between HSR and NSR1 was 0.84 while that between LSR and NSR2 was 0.74. Accuracy was not analyzed because participants' performance was at ceiling (above 90%).

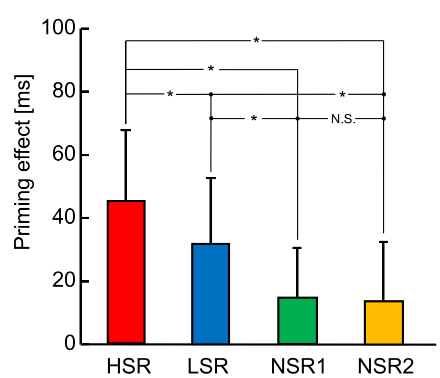

Figure 7. Experiment 2. Priming effects (difference between mean choice RTs in incongruent and congruent conditions) and standard deviation of the four prime stimulus types. HSR (High Salient Region); LSR (Low Salient Region); NSR1 (No Salient Region 1); NSR2 (No Salient Region 2). Asterisks indicate significant differences at $0.001 \leq p \leq 0.012$.

As in Experiment 1, at the end of the first experimental session, participants were asked a series of questions aimed to assess whether they had perceived the shape of the prime stimulus. The outcome of this interview was similar to that of Experiment 1: No participants reported the presence of the prime stimulus, nor its shape, even if twelve participants occasionally reported a flickering onset of the mask stimuli.

For the prime visibility task performed in the second experimental session, mean accuracy was compared to the 50% chance accuracy in one sample t test for each of the prime stimulus type conditions. None of the four mean accuracy scores was different from chance, $0.60 \leq | t_{19} | \leq 1.95$; $0.066 \leq p \leq 0.577$, providing an objective measure that none of the shapes of the four stimulus types were perceived in agreement with the participants' subjective reports.

A correlation analysis for eighty pairs (20 Participants × 4 Prime Stimulus Types) of correct response percentages in the prime visibility task and corresponding priming effect as measured by mask-choice RT task was carried out and showed that a positive correlation was not present, Pearson $r = 0.007$, $p = 0.948$. Furthermore four correlations analyses were conducted separately for each stimulus type. None of them showed positive correlation between response frequency and priming effect.

High Salient Region (Pearson $r = 0.034$, $p = 0.847$), Low Salient Region (Pearson $r = 0.207$, $p = 0.381$), No Salient Region 1 (Pearson $r = -0.199$, $p = 0.401$), No Salient Region 2 (Pearson $r = 0.019$, $p = 0.936$), and also the linear best fitting of the overall data was not significant, $y = 0.019x + 26.70$; $R^2 = 00005$.Therefore, as in Experiment 1, the lack of positive correlation demonstrated that even though some prime stimuli might have been perceived by some subjects, they did not contribute to the priming effect.

Given the results of Experiment 1, one might argue that the SR and the presence of the inducers at the four corners of the square or diamond figure played together a role in yielding the priming effect. However the only presence of the inducers yielded the weakest priming effect whereas the presence of the SR increased the strength of the priming effect roughly two- and threefold in the low and high saliency prime stimulus types, respectively, providing also a clear-cut control for the results of Experiment 1.

General discussion

The aim of this study was to test whether an unconsciously processed shape of a Kanizsa's illusory figure could influence the recognition of the shape of a real masking figure. In particular, we tested whether the unconscious processing of the SR characterizing the Kanizsa's figure could produce a priming effect even when the illusory contours delimitating the SR could not be processed by the visual system. Taking into account the model proposed by Stanley and Rubin (2003, 2005), which holds that the SR is processed by LOC while illusory contours are processed by V1 and V2 via feedback projections from LOC, we used metacontrast masking in order to prevent the processing of illusory contours (see Breitmeyer, 2007). Breitmeyer et al. (2005) hypothesized that the site of the metacontrast suppression of conscious form perception probably resides at the level of feedback projections from higher visual areas in the ventral visual stream to V1 and V2, which are necessary for the conscious perception of the attributes of objects and surfaces (Milner & Goodale, 1995; Crick & Koch, 2003). In broad agreement with this possibility, Bar and Biederman (1999) indicated V4, which is very close to LOC, as the locus of the subliminal priming phenomena.

Our results provide evidence that extends the DPST (Neumann & Klotz, 1994; Klotz & Wolff, 1995; Ansorge et al., 1998) to the SR of the Kanizsa's figure by measuring the unconscious priming effect as the difference between mean CRT to the mask shape in incongruent and congruent conditions with an SOA of 65 ms so that illusory contours could not be perceived. Overall, our results in Experiment 1 demonstrate that the unconscious processing of only the SR can lead to a significant priming effect. Furthermore, the results of Experiment 2 suggest that a modulation of the saliency of the SR leads to a modulation of the priming effect whereas its elimination strongly reduces the priming effect.

Modulation of the saliency of the SR is particularly interesting because it provides evidence for a different processing of the SR in terms of brightness enhancement and depth stratification. As described in the Methods section of Experiment 2, HSR appears more salient than LSR. While the former is a uniform surface that appears brighter than the background and is located on a plane near the observer, the latter is a nonuniform partially textured surface appearing darker than the background and without index of depth stratification. Probably depth stratification and brightness enhancement are both responsible for the differential priming effect found between HSR and LSR conditions. As far as depth stratification is concerned, this would be consistent with Mendola et al. (1999) who found a stronger functional magnetic resonance imaging signal in LOC with stimuli giving a clear impression of a solid shape occluding the background compared to stimuli that do not create strong segmentation in depth. Also Grill-Spector and Kanwisher (2001) argued in favor of an involvement of the caudal-dorsal subdivision of the LOC for the selective processing of 3-D object structure. In order to clarify the role of brightness enhancement and depth stratification in determining the priming effect different specifically selected stimuli should be used in future experiments.

The evidence of a priming effect, although very small, in the NSR1 and NSR2 is in contrast with the results of Barlasov-Ioffe and Hochstein (2009) who found no priming effect when the inducers are arranged not to form an illusory figure. Probably these conflicting results were due to different stimulus presentations: Barlasov-Ioffe and Hochstein (2009) used central and sequential; we used lateralized and simultaneous in the present study. As mentioned above, it is possible that in our NSR conditions the inducers, positioned at the four corners of the square or diamond shape, constitute a configuration or a template congruent or incongruent with respect to the real following mask and capable to pre-activate high visual areas such as LOC. This could be due to a perceptual grouping mechanism (Palmer, Brooks, & Nelson, 2003) that likely contributes to the extraction of the shape of enclosed regions, such as SR, from long term memory. It is worth pointing out that even if the amount of physical energy of each single inducer in NSR1 condition is three times bigger than in NSR2, there was no difference between priming effect in the two conditions. This confirms the possibility that the priming effect depends on the whole configuration of the inducers and, indirectly, excludes the possibility that the difference between HSR and LSR depends on the different amount of luminous energy. This is also consistent with Breitmeyer et al.'s (2005) results that highlight the role of corner parts of a shape in priming the whole shape.

The pattern of results of the present study is in agreement also with the reverse hierarchy theory (RHT) of Hochstein and Ahissar (2002). According to this theory, feed-forward activity from early to higher visual areas is totally unconscious, while conscious visual perception begins only at higher visual areas that provide a first approximate *vision at a glance* characterized by spread attention. Subsequent top-down activity provides conscious and more progressively detailed information about the stimuli as a result of focused attention. In our experiment, the prime was presented for 39 ms and the interval between prime and masking figure was 26 ms. Even though participants were not able to recognize its shape, some of them reported a flickering sensation prior to the onset of the mask. Although it is not possible to speak about vision at a glance, this perceptual effect could be considered as an index of an initial conscious experience related to activity of higher visual areas. In principle, this activity might be strong enough to pre-activate higher visual areas, presumably LOC, thus determining the priming effect and producing in some participants a first primitive conscious experience. Moreover, one might argue that participants are not able to discriminate the shape of the illusory figure and its illusory contours because, as predicted by RHT, this detailed information, which needs focused attention, is subsequently processed by feedback projections whose activity, in our case, was probably suppressed by metacontrast.

Considering that according to RHT, *vision at a glance* is characterized by spread attention, it is also possible that a portion of the larger priming effect in HSR and LSR than in NSR conditions could reflect an unconscious automatic capture of attention by SR. Indeed, when participants were keeping the gaze on the central cross they were not informed in which visual field (left vs. right) the mask could appear, and HSR and LSR could drive attention to the appropriate visual field better than NSR. One could thus argue that SR may induce an attentional shift in the appropriate visual field favoring in particular the performance in congruent trials and contributing to increase the priming effect. This is in broad agreement with Davis and Driver (1994) who found a parallel search (i.e., not affected by the number of nontargets) of Kanizsa's figure and in particular with Gurnsey, Poirier, and Gascon (1996) who found a parallel search of Kanizsa's illusory figure even in absence of illusory contours.

Our results could also be interpreted considering the distinction between iconic memory and visual working memory (VWM) as in the recent study by Ben-Shalom and Ganel (2012). These authors found a different representation of visual illusions in the two types of memory. In particular, iconic memory seems to be affected by between-objects illusions (i.e., Ebbinghaus illusion) where the relationship between the environmental context and the target is crucial. In contrast, within-object illusions (i.e., rectangle illusion as in Ganel & Goodale, 2003), where only the relationship between elements internal to the target leads to the illusion, seem not to affect iconic memory. On the other hand VWM appears to be affected by both types of illusions as if these representations were built up in time along the visual hierarchy as interactions of bottom-up and top-down systems. In the present study, the spatial relationship of the inducers of the Kanizsa figure as well as the metacontrast timing are likely to allow the visual information from the illusory figure to enter the iconic memory but not the VWM. Such an activation at an early stage in the visual processing stream could explain why only the processing of the SR takes place following metacontrast in the Kanizsa illusion: considered as a between-object illusion generated by the spatial relationship between the four inducers. Moreover the lack of conscious access to the shape of the illusory figure confirms that the four inducers were not integrated into a single unitary object as it should be if an activation of the VWM occurred. Despite that, the phenomenal impression provided by the SR entering iconic memory is clearly sufficient to guarantee a relatively complex cognitive operation as the priming effect. As such the SR feeding into iconic memory represents a global "gist" of the visual scene provided by a fast bottom up process, presumably subserved by LOC rather than a slow bottom-up buildup of information that eventually yields a complete and detailed representation of a visual object as it occurs when information reaches VWM.

In conclusion, the present study provides novel evidence that the Kanizsa's illusory figure could serve as an unconscious prime for a real figure even when the illusory contours cannot be processed and only an enclosed region such as the salient region is still available to the visual system.

Keywords: Kanizsa's figure, unconscious vision, metacontrast masking

Acknowledgments

The authors wish to thank two anonymous referees for their suggestions. This research was supported by the Italian Ministry of University and Research (MIUR).

Commercial relationships: none.
Corresponding author: Massimo Girelli.
E-mail: massimo.girelli@univr.it.
Address: Department of Neurological, Neuropsychological, Morphological and Motor Sciences, University of Verona, Italy.

References

Ansorge, U., Klotz, W., & Neumann, O. (1998). Manual and verbal responses to completely masked (unreportable) stimuli: Exploring some conditions for the metacontrast dissociation. *Perception*, *27*, 1177–1189.

Bar, M., & Biederman, I. (1999). Localizing the cortical region mediating visual awareness of object identity. *Proceedings of the National Academy of Sciences, USA*, *96*, 1790–1793.

Barlasov-Ioffe, A., & Hochstein, S. (2009). Illusory-contour figures prime matching of real shapes. *Perception, 38,* 1118–1131.

Barlasov-Ioffe, A., & Hochstein, S. (2008). Perceiving illusory contours: Figure detection and shape discrimination. *Journal of Vision*, *8*(11):14, 1–15, http//www.journalofvision.org/content/8/11/14/, doi:10.1167/8.11.14 [PubMed] [Article].

Ben A.,Ben-Shalom, & Ganel, T. (2012). Object representations in visual memory: Evidence from visual illusions. *Journal of Vision*, *12*(7):15, 1–11, http://www.journalofvision.org/content/12/7/15, doi:10.1167/12.7.15 [PubMed] [Article].

Breitmeyer, B. G. (2007). Visual masking: Past accomplishments, present status, future developments. *Advances in Cognitive Psychology*, *3*(1–2), 9–20.

Breitmeyer, B. G., & Ogmen, H. (2000). Recent models and findings in visual backward masking: A comparison, review, and update. *Perception and Psychophysics*, *62*(8), 1572–1595.

Breitmeyer, B. G., Ogmen, H., Ramon, J., & Chen, J. (2005). Unconscious and conscious priming by forms and their parts. *Visual Cognition*, *12*(5), 720–736.

Davis, G., & Driver, J. (1994). Parallel detection of Kanizsa subjective figures in the human visual system. *Nature*, *371*, 791–793.

De Weert, C. M. M., & Kruysbergen, A. W. H. (1987). Subjective contour strength and perceptual superimposition: transparency as a special case. In S. Petry & G. Meyer (Eds.), *The perceptions of illusory contours*. New York: Springer.

De Weert, C. M. M., & Spillmann, L. (1995). Assimilation: Asymmetry between brightness and darkness. *Vision Research*, *35*(10), 1413–1419.

Crick, F., & Koch, C. (2003). A framework for consciousness. *Nature Neurosciences*, *6*, 119–126.

Ganel, T., & Goodale, M. A. (2003). Visual control of action but not perception requires analytical processing of object shape. *Nature*, *426*, 664–667.

Gellatly, A. R. (1980). Perception of an illusory triangle with masked inducing figure. *Perception*, *9*, 599–602.

Grill-Spector, K., & Kanwisher, N. (2001). The lateral occipital complex and its role in object recognition. *Vision Research*, *41*, 1409–1422.

Gurnsey, R., Poirier, F. J., & Gascon, E. (1996). There is no evidence that Kanizsa-type subjective contours can be detected in parallel. *Perception*, *25*, 861–874.

Hochstein, S., & Ahissar, M. (2002). View from the top: Hierarchies and reverse hierarchies in the visual system. *Neuron*, *36*, 791–804.

Imber, M. L., Shapley, R. M., & Rubin, N. (2005). Differences in real and illusory shape perception revealed by backward masking. *Vision Research*, *45*, 91–102.

Kanizsa, G. (1987). Quasi-perceptual margins in homogeneously stimulated fields. In S. Petry & G. Meyer (Eds.), W. Gerbino (Trans.), *The perception of illusory contours* (pp. 40–49). New York: Springer. (Original work published 1955).

Kentridge, R. W., Nijboer, T. C. W., & Heywood, C. A. (2008). Attended but unseen: Visual attention is not sufficient for visual awareness. *Neuropsychologia*, *46*, 864–869.

Klotz, W., & Wolff, P. (1995). The effect of a masked stimulus on the response to the masking stimulus. *Psychological Research*, *58*, 92–101.

Lesher, G. W., & Mingolla, E. (1993). The role of edges and line-ends in illusory contour formation. *Vision Research*, *33*(16), 2253–2270.

Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information*. San Francisco, CA: W. H. Freeman.

Mendola, J. D., Dale, A. M., Fischl, B., Liu, A. K., & Tootell, R. B. H. (1999). The representation of illusory and real contours in human cortical visual areas revealed by functional magnetic resonance imaging. *The Journal of Neuroscience*, *19*(19), 8560–8572.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford, UK: Oxford University Press.

Murray, M. M., Wylie, G. R., Higgins, B. A., Javitt, D. C., Schroeder, C. E., & Foxe, J. J. (2002). The spatiotemporal dynamics of illusory contour processing: Combined high-density electrical mapping, source analysis, and functional magnetic resonance imaging. *The Journal of Neurosciences*, *22*(12), 5055–5073.

Neumann, O., & Klotz, W. (1994). Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification?. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV* (pp. 123–150). Cambridge, MA: MIT Press.

Nieder, A. (2002). Seeing more than meets the eye: Processing of illusory contours in animals. *Journal of Comparative Physiology*, *188*, 249–260.

Palmer, S. E., Brooks, J. L., & Nelson, R. (2003). When does grouping happen? *Acta Psychologica*, *114*, 311–330.

Reynolds, R. I. (1981). Perception of an illusory contour as a function of processing time. *Perception*, *10*, 107–115.

Ringach, D. L., & Shapley, R. (1996). Spatial and temporal properties of illusory contours and amodal boundary completion. *Vision Research*, *36*(19), 3037–3050.

Rock, I., & Linnet, C. M. (1993). Is a perceived shape based on its retinal image? *Perception*, *22*, 61–76.

Seghier, M. L., & Vuilleumier, P. (2006). Functional neuroimaging findings on the human perception of illusory contours. *Neuroscience and Biobehavioral Reviews*, *30*, 595–612.

Spillmann, L. (2009). Phenomenology and neurophysiological correlations: Two approaches to perception research. *Vision Research*, *49*(12), 1507–1521.

Spillmann, L., & Dresp, B. (1995). Phenomena of illusory form: Can we bridge the gap between levels of explanation? *Perception*, *24*, 1333–1364.

Stanley, D. A., & Rubin, N. (2003). fMRI activation in response to illusory contours and salient regions in the human lateral occipital complex. *Neuron*, *37*, 323–331.

Stanley, D. A., & Rubin, N. (2005). Rapid detection of salient region: Evidence from apparent motion. *Journal of Vision*, *5*(9):4, 690–701, http://www.journalofvision.org/content/5/9/4, doi:10.1167/5.9.4 [PubMed] [Article].

Ulrich, R., & Miller, J. (1994). Effects of truncation on reaction time analysis. *Journal of Experimental Psychology*, *123*(1), 34–80.

Varin, D. (1971). Fenomeni di contrasto e diffusione cromatica nell'organizzazione spaziale del campo percettivo. [Contrast and chromatic diffusion phenomena in the organization of the perceptive field]. *Rivista di Psicologia*, *65*, 101–128.