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**Blame the Usual Contexts:
New Findings on Illusory Contours and Visual Masked Priming
by using Novel Contexts**

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General Introduction

Perception depends on the context; this is why different contexts are likely to induce different perceptions. Therefore, the role of the researcher is to identify which contexts may enable her/him to draw conclusions on mechanisms underlying perception. After all, the difference between the control and the experimental condition in scientific research can be seen as a change in a specific aspect of the context: all being equal, except the independent variable.

The importance of the context in perception is perhaps secondary only to its vastness and complexity. Here, we choose two distinct topics as research issues: an “old” problem, the formation of illusory contour surfaces, and a “new” one, the origins of visual masked priming.

Illusory contours have been widely researched: Pughé and Coren (1992a) counted more than 400 publications from 1900 to 1990. In recent times, studies employing new technologies and instruments extended this list. However, just a few of them deal with illusory contour figures in heterogeneous contexts, i.e., depicted against non-homogeneous backgrounds. The first part of this work illustrates five experiments which attempt to fill this gap. Particular attention was paid to depth stratification, a phenomenal percept that in the past has received less attention: direct (Chapter 1) and indirect (Chapter 2) methods were employed to measure this percept, as well as illusory contour clarity and brightness enhancement.

The employment of heterogeneous backgrounds and illusory contour configurations can give rise to particularly striking visual illusions. Here we present a new one, called the “Illusory Contoured Tilting Pyramid” (Chapter 3). Two experiments were run to establish the causal role of illusory contours.

In the second part of this work, we report a series of visual masked priming experiments that focused on between-trials factors: namely, frequency of occurrence and presentation order effects (Chapter 4). Previous research on priming has taken into account primarily the frequency of congruent and incongruent trials, and in particular the prime validity effect: when the proportion of valid trials is higher than invalid trials, an increase in priming is obtained. However, standard randomization of stimuli was usually employed for presentation, making frequent stimuli more likely to occur on the initial trials. Thus, the effects of initial and overall stimulus frequencies have become intermingled. The new context employed here (a biased presentation order) shed some light on these effects. Results are in

agreement with the recently proposed retroactive view of masked priming, in contrast to the classic spreading activation theories (Masson & Bodner, 2003).

1. Depth stratification on heterogeneous backgrounds is independent from illusory contour clarity and brightness enhancement.

1.1. Introduction

The formation of illusory contour figures may be observed in several contexts (Purghé 1991; Halpern, Salzman, Harrison, & Widaman, 1983). One of the most widely recognized and investigated was introduced by Kanizsa (1955), who arranged three circles from which a sector was removed (“pacman” tokens, or pacmen) at the corners of an imaginary triangle. The missing sector coincides with the portion of the circle that the imaginary triangle may overlay. Three outline corners are also positioned symmetrically between the pacmen (fig. 1). In the Kanizsa figure, the perception of an illusory contour is associated with brightness enhancement: the illusory triangle appears brighter than the background.

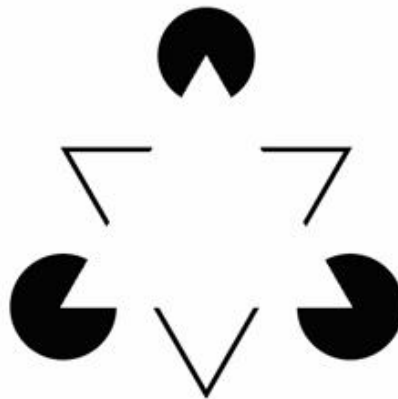


Figure 1.1. The widely-known Kanizsa triangle. Black sectors and outline corners are symmetrically placed on a uniform white plane. However, all observers reported they perceived a white triangle upon a outline triangle and three back disks. Furthermore, the illusory triangle is perceived as brighter than the background.

These two phenomenal attributes – illusory contour and brightness enhancement – have been widely researched (see for comprehensive reviews: Petry & Meyer, 1987; Leshner, 1995). A third phenomenal percept has received much less attention, i.e. depth stratification

(Pinna, Ehrenstein, & Spillmann, 2004; Halpern et al., 1983; Watanabe & Oyama, 1988): the illusory shape appears to lie on a plane nearer to the observer. This aspect was considered to be crucial by the earliest theories about illusory contour formation (Halpern & Salzman, 1983; Purghé & Coren, 1992a). Kanizsa claimed the inducers' amodal completion to be the cause of depth stratification, and thus the phenomenon underlying illusory contour figure formation (Kanizsa, 1955, 1974, 1976). Coren (1972) with his "implicit depth cue" theory claimed that the first cause of illusory contour appearance is a depth stratification process promoted by depth cues (such as interposition) within the inducers. Gregory (1972) proposed that the existence of the illusory object is postulated as a perceptual hypothesis to account for the interposition cues in the inducers.

Several authors, however, demonstrated that it is possible to perceive illusory contours and brightness enhancement even when inducers are not subject to completion (Pinna et al., 2004; Purghé & Coren, 1992b; Purghé, 1991; Day & Kasperczyk, 1983; Kennedy, 1978; Ware & Kennedy, 1977) and when occlusion clues are not present (Purghé, 1995), thus excluding the possibility that depth stratification is the sole cause for the formation of an illusory contour.

Some key studies clearly demonstrated that illusory contour clarity and brightness enhancement may be influenced separately by manipulating the position and aspect of inducers (Leshner & Mingolla, 1993; Banton & Levi, 1992; Shipley & Kellman, 1992b; Petry, Harbeck, Conway, & Levey, 1983). But ultimately very little is known about depth stratification, although some authors did highlight its importance in a review paper on the determination of illusory contours (Halpern et al., 1983). In a recent study, Pinna et al. (2004) manipulated an edge-type Ehrenstein configuration, showing that apparent depth can be dissociated from the formation of illusory contours and brightness enhancement. Hence, it should manifest independently of the strength of the other two phenomena – brightness enhancement and illusory contour clarity.

The depth stratification percept is quite ephemeral in common conditions (i.e., against a homogeneous background) (*ibid*); however, it can be strongly enhanced when the pacmen are seen against a heterogeneous background (Purghé, 1998). In figure 2, we have reproduced different configurations in order to allow comparison of the effects induced by the same pacmen in different contexts.

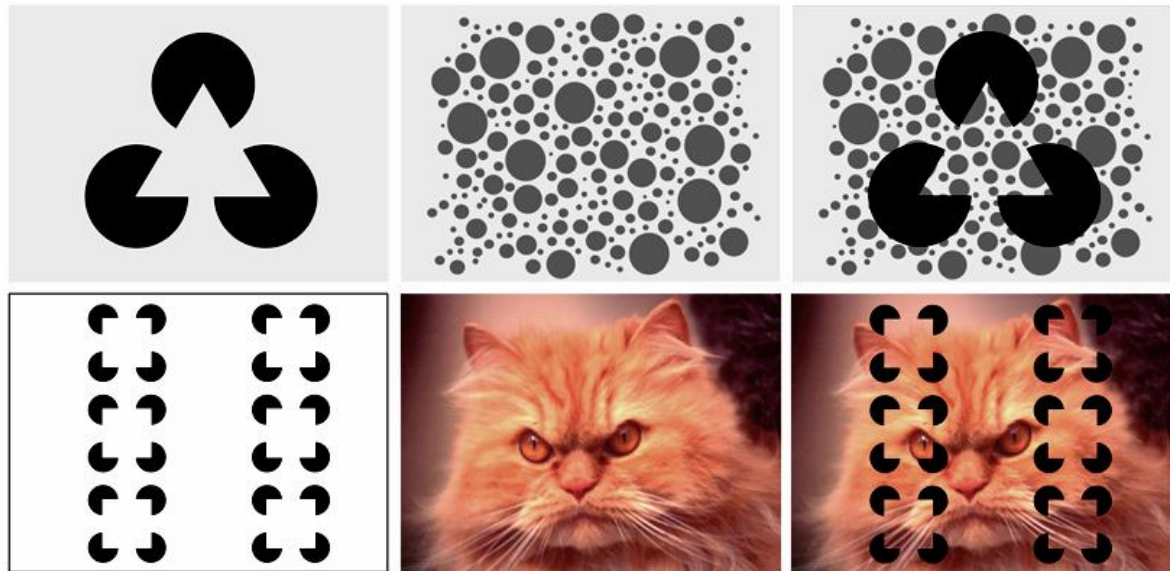
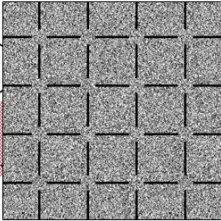
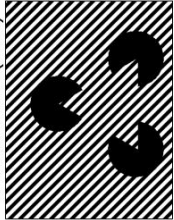
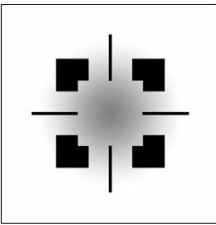
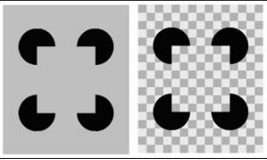
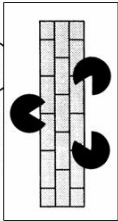
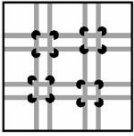
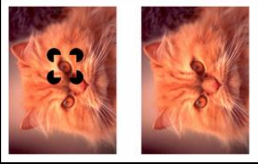


Figure 1.2. Enhanced depth stratification. When illusory contour figures (left) are superimposed on heterogeneous backgrounds (center), depth stratification is strongly enhanced (right). At the top, an illusory triangle is placed on a bubble background: A strong depth displacement is reported. Bottom, the “Layered Cat”: Depth stratification persists in real-world pictures despite several depth cues acting in opposition: texture gradient, size constancy, blur, real luminance edges.

A similar observation in Ehrenstein grids was also reported by Spillmann & Redies (1981): when a random dot screen is used as a background, the circular patches seem to “bulge forward through the gaps or even appear to lie wholly in front of the thin lines” (*ibid*, p 411). In a recent paper, van Lier, de Wit, & Koning (2006) superimposed an illusory square defined by pacmen on a grid of bars and reported that the parts of the grid within the illusory square were perceived as clipped and shifted.

Table 1.1. Illusory Contours on Heterogeneous Backgrounds. In this table, we summarized studies of illusory contour figures in heterogeneous contexts present in the literature. It can be easily seen that the three defining features (illusory contour clarity, brightness enhancement, depth stratification) had never been investigated together. Question marks represent lack of information on the specific dimension for the specified study (reproduced from Guardini (2007)).

Illusory Contour Clarity	Random Dots Spillmann (1977) 	?							
Brightness Enhancement	Stripes Rock and Anson (1979) 	Abolished – but “Only when stripes are placed behind inducers”							
Depth Stratification	Radial gradient Parks (1982) 	?							
	Checkerboard Ramachandran et al. (1993) 	More – “Enhanced Illusory Contours” effect							
	Brick Pattern Takahashi (1994) 	Less – “The noise figures do not completely disturb the perception of IC”							
	Grid of Bars Van Lier et al. (2006) 	Restlessness – “the part of the grid within the illusory square appear as clipped and shifted”							
	Real World Picture Purghé (1998) Lambertini 	?							
									More: lens or stratification effect?

In our opinion, this issue has not received enough attention. One possible reason can be that the use of a heterogeneous background raises questions about the influence of background visual elements on the formation of illusory contour figures. For example, one may hypothesize that heterogeneous contexts may contain linear units that encourage the formation of an illusory edge. Ramachandran, Cobb, Rogers-Ramachandran, & Tyler (1993) indeed reported a considerable enhancement of illusory contour clarity when the contours are coincident with real luminance edges inside a checkerboard, in comparison to a homogeneous context (“enhanced illusory contours” effect, *ibid*, p. 3146). When illusory contours are misaligned but still parallel to the borders of the checks, the contours of the checks nearest to the illusory square appear enhanced. How depth stratification is affected by the interaction between illusory and real contours has not been studied. The effect of linear background elements that are not parallel to the illusory contours has also yet to be explored. However, linear elements have been studied as illusory contour inducers: Gillam investigated a variety of arrangements for inducing linear elements and demonstrated that randomly-oriented lines terminating on an illusory contour brightened it comparatively to consistently-oriented lines (Gillam, 1987).

There have been few attempts to display Kanizsa configurations on heterogeneous backgrounds to investigate any (or all) of the three dimensions – brightness enhancement, illusory contour clarity and depth stratification. In addition to Ramachandran et al (*ibid*), we located only three other studies: Parks (1982), Takahashi (1994) and Rock and Anson (1979). The first author reports that, when an illusory figure is presented against a physical lightness gradient (a radial gradient from grey to white), brightness enhancement of the illusory figure is often the reverse of the usual effect. Takahashi observes that noise-containing backgrounds (a brick-pattern) do not affect contour clarity of the Kanizsa triangle configuration in comparison to white-background conditions when they are presented tachistoscopically. Rock and Anson report that the presence of a 45° oriented striped background can eliminate the perception of an illusory triangle.

From these results, one obvious consideration arises: heterogeneous backgrounds affect the three dimensions mentioned above diversely, and the resulting effects are clearly closely related to the aspect of the background employed. In Ramachandran et al (1993), the result is contour clarity enhancement; in Parks (1982), a reversal of the surface brightness enhancement effect, while Takahashi (1994) and Rock and Anson (1979) record contradictory effects on contour clarity. Respectively, a checkerboard, a luminance gradient, a brick- and a

striped-pattern were used as backgrounds. None of the authors mention the other two dimensions.

By using homogeneous *and* heterogeneous backgrounds, we wish to investigate the depth stratification percept induced by edge-type illusory contour figures. In particular, we tested two hypotheses: (1) A heterogeneous background enhances depth stratification; (2) Depth stratification is independent of variation in illusory contour clarity and brightness enhancement.

In the first experiment, ratings of illusory contour clarity, brightness enhancement and depth stratification were taken with homogeneous and heterogeneous backgrounds. In the second, texture coarseness was manipulated to verify the independence of depth stratification from the other two features.

1.2 Experiment 1

The goal was to investigate whether depth stratification ratings are higher with heterogeneous backgrounds. An illusory contour square configuration was superimposed on a monochromatic Gaussian noise background. Subjects' depth stratification ratings were collected. Orientation of the illusory square was manipulated, following Ramachandran et al (1993). In particular, a condition in which illusory contours are not parallel to the real luminance edges within the background was included (i.e., illusory diamond configuration on square-checks textures). Size of the illusory squares was also manipulated. Subjects were also asked to evaluate illusory contour clarity and brightness enhancement.

1.2.1 Methods

Subjects. A total of 18 subjects aged 22 to 33 (mean age 26), 9 males and 9 females, participated in the first experiment. All subjects were undergraduate students of the Department of Psychology at Padua University and were naïve regarding the purpose of the experiment. All had normal or corrected-to-normal vision.

Stimuli and Apparatus. Stimuli were full screen images with a size of 1280x1024 pixels

with a standard resolution of 72 pixels per inch (28.3 pixels per cm). At the viewing distance of 91 cm, the images subtended 27.9 x 22.5 degrees of visual angle. The inducers were black pacmen (luminance value: 2 cd/m²) of three different sizes (diameter lengths: 3.3, 2.5, 1.6 deg), subtending illusory square regions of three different sizes (square side lengths: 5.2, 3.8, 2.6 deg respectively). The *support ratio*, as defined by Shipley & Kellman (1992b), was maintained fixed with a value of 0.67: that is, the distance between the centres of any two consecutive inducers always measured three times the radius of the inducers themselves. The three configurations were presented either 1) with no rotation (“square” configurations) or 2) with a 45° rotation (“diamond” configuration). The illusory figures were positioned at the centre of the screen.

Two backgrounds were employed: one homogeneous grey and one heterogeneous textured Gaussian-noise. The sides of the monochromatic square checks measured 7 pixels (at an observation distance of 91 cm: 0.2 deg of visual angle); thus texture coarseness measured 6.5 pixels/degree. The distribution of luminance values between black and white was represented by a histogram with a Gaussian distribution (Chubb, Econopouly, & Landy, 1994). Mean luminance value of both backgrounds was 40 cd/m². A total of 12 stimuli were built, using Photoshop 6.0 by Adobe. Stimuli are presented in figure 3 and in table 2.

Three 19 inches NEC CRT monitors of the same type (model: MultiSync 95F) and with the same settings were employed in this experiment. A central monitor was used to display stimuli and two other monitors, placed one at each of its sides, were used to display anchor stimuli throughout the experimental session. Refresh rate of the three monitors was 85 Hz. Desktop size was set at 1280x1024 pixels with a 32-bit colour depth. E-Prime software version 1.1 (Psychology Software Tools, 2001) was employed to control stimuli presentation and to record subjects ratings.

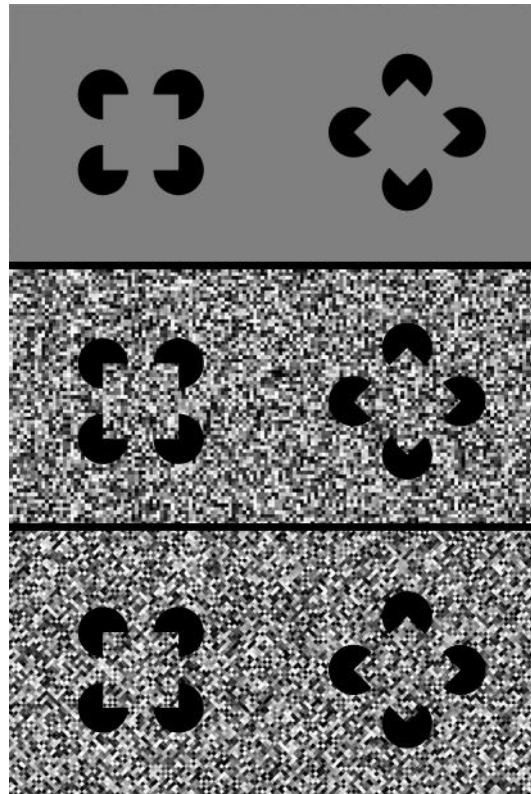


Figure 1.3. Stimuli from Experiments 1 and 2. Square and diamond configurations placed on a homogeneous grey background (top row) and on textured backgrounds: the background is made of either square (center row) or diamond tiles (bottom row). The length of the side of each tile is 7 pixels (0.153 deg at viewing distance); texture coarseness is 6.54 pixels / degree. Illusory configurations were presented in three different sizes in experiment one; in experiment two, background texture coarseness was manipulated (see text for details). Stimuli are not in scale.

Procedure. A rating scale procedure was used to measure the perceived strength of illusory contour clarity, brightness enhancement and depth stratification on a 9 point scale; “1” was the weakest effect strength. Anchor stimuli corresponding to the highest and lowest values were displayed on two different monitors during the whole experimental session. The anchor stimuli are presented in fig 4. Subjects were told that the three effects were present in all the stimuli they were to rate, but to different degrees.

Ratings of the three dimensions were collected in three different blocks; in each block, each subject progressed through all the 12 stimuli at his own pace, with a 2 seconds blank display between each rating. Block presentation order and stimuli presentation order were randomised between subjects. Subjects viewed the stimuli with both eyes using a head- and chinrest positioned at 91 cm from the central monitor to ensure correct observation distance.

All observations were carried out in a dimly lit room.

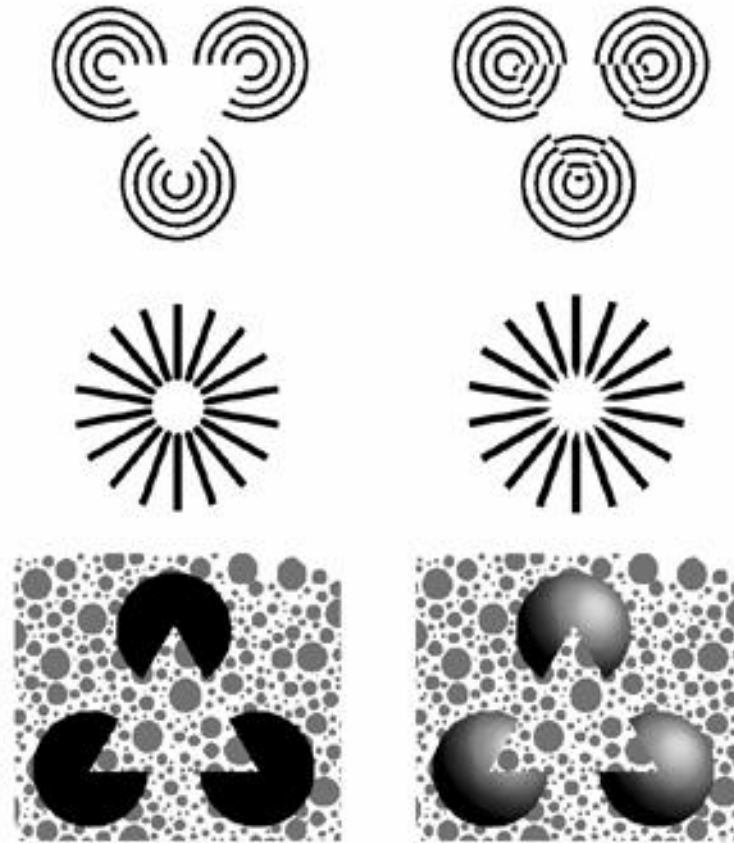


Figure 1.4. Stimuli employed to explain to subjects the three corresponding dimensions. In the first row, arc-like inducers showed contour clarity accompanied (left) or not (right) by brightness enhancement. In the second row, Ehrenstein configurations were used to show a low (left) or high (right) brightness enhancement. These are the same stimuli used by Leshner & Mingolla (1993). In the third row, Kanizsa triangles on a bubble background were used to show a low (left) or high (right) depth stratification.

1.2.2 Results and discussion

Three repeated measure ANOVAs were performed on data relative to illusory contour clarity, brightness enhancement, and depth stratification. The Greenhouse-Geisser procedure was used to adjust degrees of freedom when the sphericity assumption was not met. Student's t-test with Bonferroni correction was used for multiple comparisons. No illusory square size effects were found. This allowed us to pool ratings across the three levels of the square size factor. Average ratings are discussed separately.

(a) *Illusory contour clarity.* A significant interaction ($F_{(1,17)} = 7.581, p < 0.05$) between background type and illusory square orientation was found. Post-hoc comparisons

demonstrated that illusory contours are perceived with increased clarity when they form a square against the heterogeneous background (mean ratings: square on homogeneous background = 5; square on heterogeneous background = 6.1; $t = -2.698$, $d.f. = 53$, $p < 0.05$). The square-tiled textured background proved to enhance contour clarity ratings to a greater extent in square configurations, perhaps thanks to the supporting role of real luminance edges. When the alignment is not met (diamond configurations), contour clarity ratings are lower. This finding is in agreement with Ramachandran et al. (1993). Examining linear inducers, Kennedy (1988) highlighted the importance of the shape of the end of the bars acting as inducers, not just their main axis or longer contour. In particular, the real edge that follows the illusory contour plays a key role: for example, if squared-off bar inducers are not parallel to the illusory contours, the effect is minimal (*ibid*, fig.3). His results suggest an alternative explanation to the contour clarity enhancement we recorded: the diamond configuration's illusory contours may be hampered to a greater extent in respect to the square configuration because of real contours that cut across them.

(b) *Brightness Enhancement*. No significant differences in brightness enhancement were found when the background changes from the homogeneous condition to the heterogeneous one.

(c) *Depth Stratification*. Depth stratification ratings were higher when Kanizsa configurations were superimposed on the heterogeneous background, in both square and diamond configurations ($F_{(1,17)} = 42.843$, $p < 0.05$. Mean ratings: configurations on homogeneous background = 3.1; configurations on heterogeneous background = 5.8).

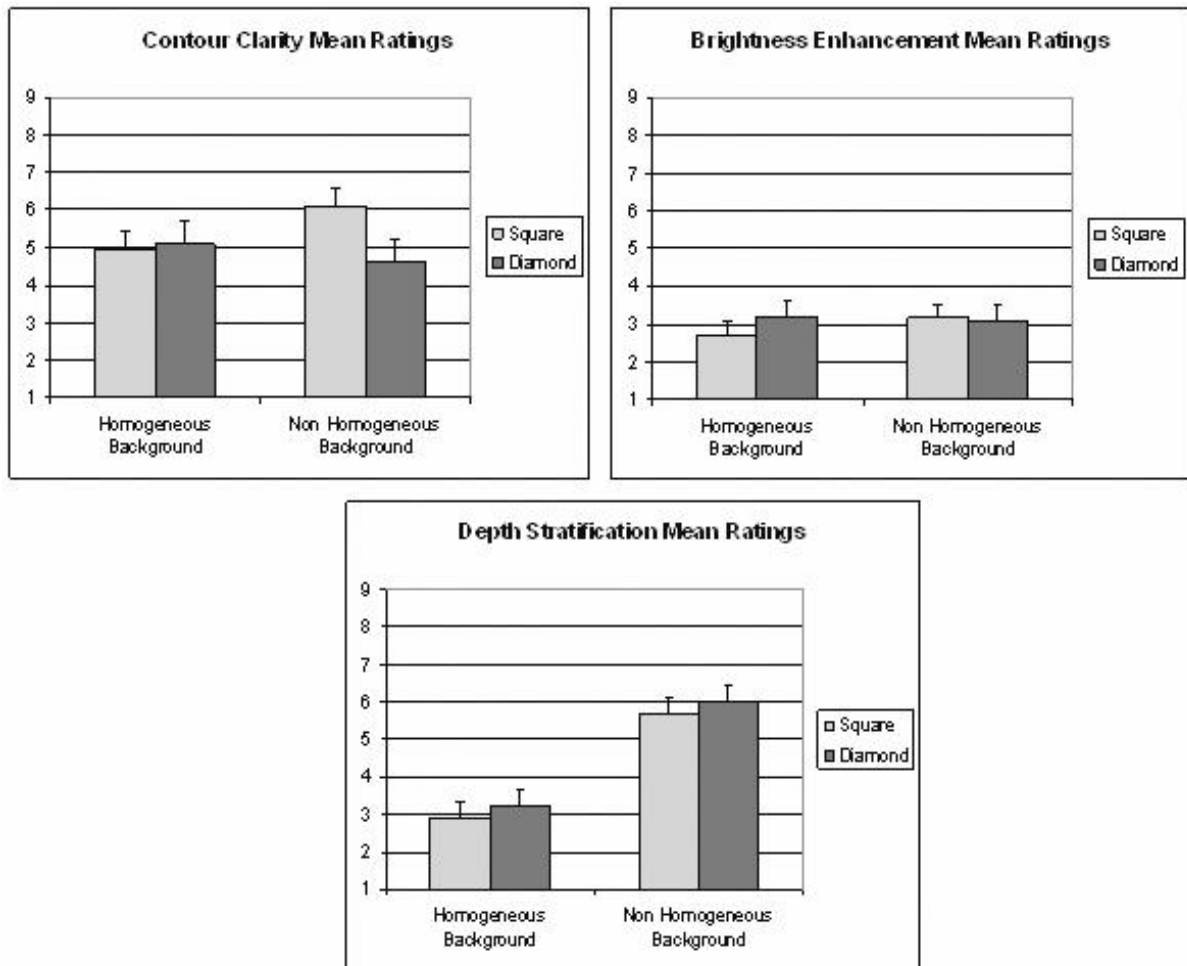


Figure 1.5. Results of Experiment 1. Ratings were pooled across the three levels of square size factor, because no significant differences were found. The “enhanced illusory contour” effect (top left): contour clarity is enhanced only when alignment between illusory and real contours is present. The enhanced depth stratification effect (bottom): depth stratification is enhanced by the heterogeneous background. Error bars represent standard error.

These findings support our first hypothesis. Depth stratification is enhanced when inducers are depicted against a heterogeneous background in comparison to a homogeneous one. Furthermore, the percept does not show appreciable differences between the square and diamond configuration. This suggests that depth stratification is not affected by the alignment between illusory contours and real luminance edges in the background. On the other hand, illusory contour clarity is enhanced when this alignment is met. This leads us to exclude that the depth stratification effect here documented can be accounted for by the “enhanced illusory contours” effect (Ramachandran et al., 1993), which was found in contour clarity ratings. Brightness enhancement is not affected by the heterogeneous background.

Mean luminance value:	Texture Coarseness	Texture Checks Size		
40 cd/m ²	Pixels/Degree			
	(at an observing distance of 91 cm)	Pixels	mm	deg

Experiment 1

Homogeneous Background	-	-	-	-
Heterogeneous Background (Coarseness value 7)	6.54	7	2.47	0.153

Experiment 2

Coarseness value 1	45.45	1	0.35	0.022
Coarseness value 2	22.73	2	0.71	0.044
Coarseness value 4	11.36	4	1.41	0.088
Coarseness value 6	7.52	6	2.12	0.133
Coarseness value 8	5.65	8	2.82	0.177
Coarseness value 10	4.50	10	3.53	0.222

Table 1.2. Description of stimuli used in experiments 1 and 2. For heterogeneous backgrounds, texture coarseness and checks size are also reported. Viewing distance was 91 cm.

1.3 Experiment 2

One result from experiment one suggested that depth stratification is independent of alignment between illusory contours and real luminance edges within the texture, while illusory contour clarity seems to depend on this alignment. In the second experiment, we aimed to verify this finding throughout a range of background texture coarseness values. By increasing this value, the linear elements within textures become longer (i.e., the tiles become bigger); since the length of the real edge of the inducers has an effect both on brightness enhancement (Ehrenstein, 1941) and contour clarity (Shipley & Kellman, 1992), we asked ourselves whether the length of linear elements within the texture would also be relevant. Specifically, in Ehrenstein configurations, the brightness of the central area is found to be dependent on the length of the rays: if the lines do not have the necessary minimal length to

induce the effect, no brightness enhancement is seen. Furthermore, illusory contour clarity can be enhanced or reduced by respectively increasing or decreasing the length of physically given edges that belong to the inducers. A second objective was the comparison of the perceptual course of the three percepts among the texture coarseness levels, to test depth stratification independency from the other two phenomena – illusory contour clarity and brightness enhancement.

Rating scale procedure was employed to collect data about depth impressions generated by Kanizsa figures against textured backgrounds with different coarseness. A new set of stimuli was built by superimposing illusory configurations on Gaussian noise textures with different coarseness: check-side length varied between 1 and 10 pixels (corresponding to texture frequencies between 45.5 and 4.5 pixels/degree; cf. table 2 for details). Square and diamond configurations were employed on textures made of both square and diamond tiles. The latter were produced by rotating the texture to an angle of 45°. Subjects were also asked to rate contour clarity and brightness enhancement.

1.3.1 Methods

Subjects. The eighteen subjects who participated in the first experiment also served as participants in the second experiment, which was carried out in a separate session.

Stimuli and Procedure. Stimuli were full-screen images with the same features of stimuli used in experiment 1. Size of illusory figures was not manipulated in this case: the inducers were all black pacmen with a diameter of 3.3 deg that subtended an illusory square region with a side of 5.2 deg. Square and diamond configurations were employed. Six different Gaussian noise backgrounds were built; tile side measures were 1, 2, 4, 6, 8 and 10 pixels respectively (see table 2 for details). The textures were rotated at an angle of 45° to produce diamond tile backgrounds. A total of 24 stimuli were built, 12 with alignment between illusory contours and real luminance edges within the texture (illusory square on square tiles and illusory diamond on diamond tiles) and 12 without (illusory square on diamond tiles and illusory diamond on square tiles). Apparatus and procedure were identical to the one employed in experiment 1.

1.3.2 Results and discussion

One repeated measures ANOVA was performed. The Greenhouse-Geisser procedure was used to adjust degrees of freedom when the sphericity assumption was not met. Student's t-test with Bonferroni correction was used for multiple comparisons. Average ratings are discussed separately and presented in figures 1.6 and 1.7.

(a) *Illusory contour clarity*. A significant main effect for the alignment factor suggested that real contours within the background enhanced the clarity of illusory contours, but only when the former were aligned or parallel to the latter (mean ratings: alignment present = 4.6; alignment not present = 4, $F_{(1,17)} = 5.011$, $p < 0.05$). Illusory contour ratings were not affected by texture coarseness alone, or by an interaction between alignment and coarseness.

(b) *Brightness Enhancement*. A significant main effect for texture coarseness ($F_{(2.546,43.284)} = 4.136$, $p < 0.05$) and post-hoc comparisons suggested that average ratings followed an inverted U curve. Coarseness value 2 was lower than 4 (mean ratings: 2.9 and 3.7; see fig. 7) and value 6 higher than 8 (mean ratings: 3.7 and 3.2; see fig. 1.7). However, extreme values of coarseness (1 and 10) do not differ from the intermediate levels.

(c) *Depth Stratification*. Texture coarseness affected depth stratification ratings in a significant way ($F_{(2.195,37.309)} = 9.033$, $p < 0.05$). Post-hoc comparisons indicated that ratings increase from coarseness values 1 to 4, and then stabilize. The mean rating of the texture with the smallest tiles (coarseness value 1) is lower than textures with larger tiles (coarseness value 4, 6, 8, and 10); the texture with coarseness value of 2 falls between these two sets. Subjects gave higher depth stratification ratings when illusory configurations were displayed on textures composed of larger tiles. Average ratings range is between 3 and 5.2 (fig. 1.7).

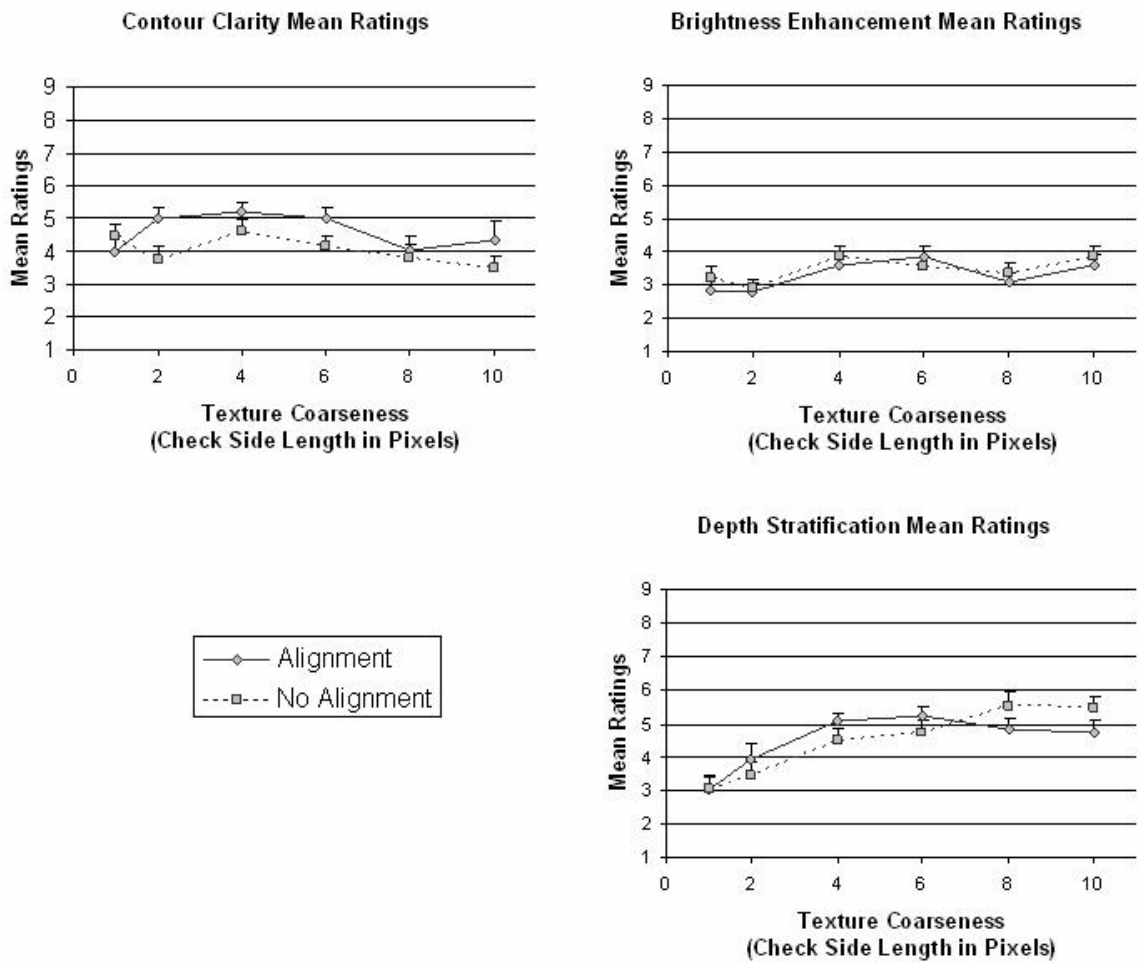


Figure 1.6. Results from Experiment 2. Ratings of contour clarity, brightness enhancement and depth stratification are presented as a function of texture coarseness and alignment factors. Error bars represent standard error.

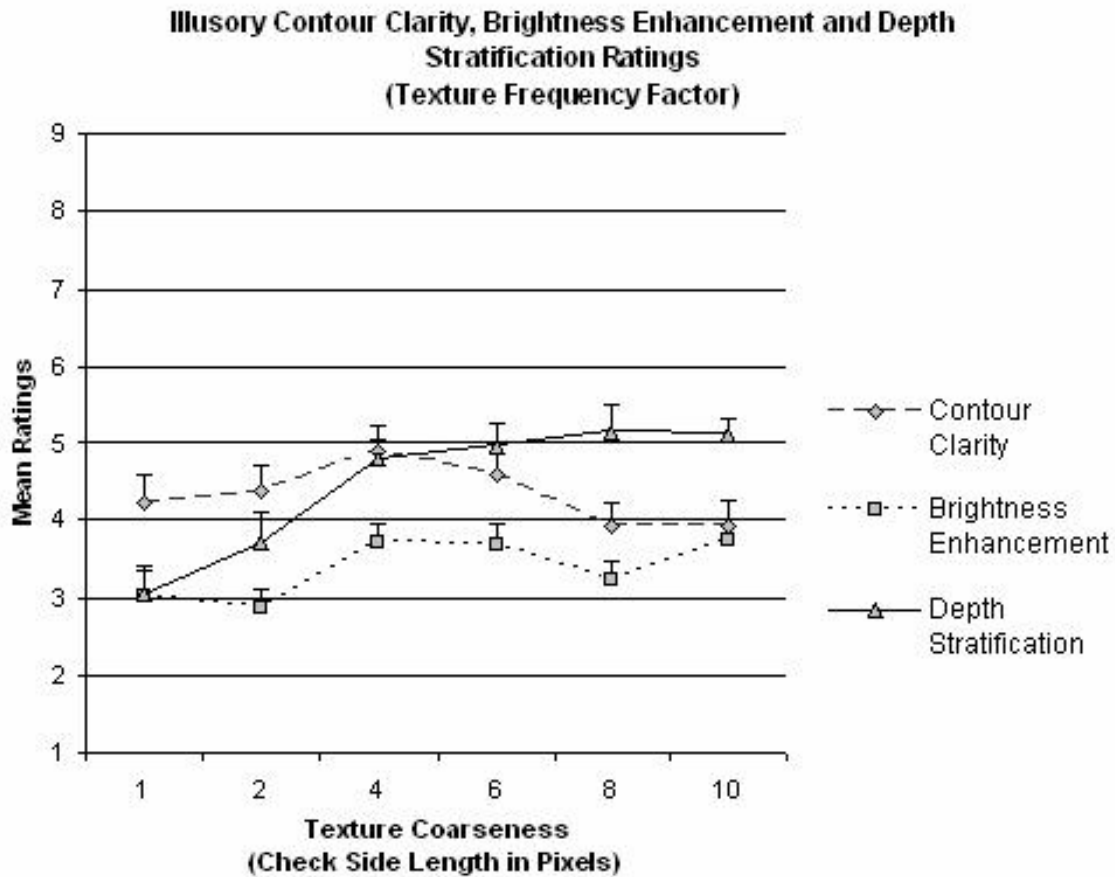


Figure 1.7. Results from Experiment 2. Ratings were pooled as a function of texture coarseness. Contour clarity average ratings are not significantly affected by the coarseness of the texture. Brightness enhancement ratings seem to partially follow an inverted U curve: significant differences between coarseness levels were found between coarseness levels 2 and 4, 6 and 8; the two extreme values do not differ from the intermediate ones. Depth stratification ratings follow an S-shaped curve: differences are found between coarseness levels 1 and 4, 6, 8, 10, while texture with coarseness value of 2 lies between these two sets. Error bars represent standard error.

A significant interaction between alignment and texture coarseness was found ($F_{(5,85)} = 3.562, p < 0.05$). Subsequent repeated contrast analysis showed that there was a significant difference between the “alignment present” and “alignment not present” conditions only between texture coarseness values 6 and 8 ($F_{(1,17)} = 9.275, p < 0.05$): Alignment with real luminance edges seems to lower depth stratification ratings when larger tiles are in the background, in comparison to the conditions in which alignment is not present.

A second objective was to compare the effects of texture coarseness on illusory contour clarity and brightness enhancement. Average ratings for the three dimensions are plotted in figure 7. Texture coarseness and the aspect under consideration (contour clarity, brightness enhancement or depth stratification) were considered as within factors in a repeated measures ANOVA. A significant interaction between the two factors was found ($F_{(10,170)} = 7.235, p < 0.001$), meaning that the three percepts are diversely affected by the texture manipulation. To better describe this issue, curve estimation procedure was performed on pooled data to find which type of regression equation provides the best description of the relationship between texture coarseness and ratings for the three dimensions. Only depth stratification met statistical significance: data can be described using a S-curve ($F_{(1,4)} = 103.472, p = 0.001; R^2 = 0.963$), in agreement with our preliminary observations.

1.4 General Discussion

In two experiments, (1) Gaussian noise background produced enhanced depth stratification, and (2) depth stratification was found to be independent of contour clarity and brightness enhancement. A result similar to the first one was reported by Spillmann & Redies (1981) using line-end inducers on a random-dot pattern. We have extended this observation to edge-type inducers. As Pinna et al. (2004) suggested, the depth stratification effect is not a prerequisite for illusory contour and brightness enhancement.

The alignment between illusory contour and real luminance edges within the texture affected the three percepts in different ways. Illusory contour clarity was enhanced, no matter the size of background elements. This result confirms and extends the findings by Ramachandran et al. (1993). Brightness enhancement was not affected by alignment. Depth stratification is affected by alignment only when the texture coarseness factor is also considered. Within the coarseness range we considered, the lack of alignment gave higher

depth stratification ratings only with larger tiles in the background. However, it is possible to exclude that the depth stratification effect can be accounted for by the “enhanced illusory contours” effect (ibid).

Why a heterogeneous background magnifies depth stratification in illusory contour figures is unclear. We will discuss some hypotheses about the possible underlying mechanisms with regard to this effect.

It seems reasonable to claim that the only difference between the two types of displays (homogeneous / heterogeneous) is the presence of elements inside and outside the illusory surface (fig 2). When the illusory surface emerges, it could be that the elements inside it are pushed on a depth plane nearer to the observer, as observed in the phenomenon called “stereo capture”. By using an illusory square viewed stereoscopically on a textured background, Ramachandran & Cavanagh (1985) demonstrated that when small horizontal disparities are given to the vertical edges of the cut sectors, the texture is “captured” and perceived on the top of the illusory surface. Is it possible that a similar effect can take place without any horizontal disparities?

Interestingly, Vallortigara & Bressan (1994) proposed an explanation of stereo capture based on a conflict between information provided by vertical disparities and occlusion. They suggested that capture is limited to texture elements enclosed in the illusory figure because of ambiguous occlusion information at the monocular level. In fact, texture elements at the periphery of the pattern appear to be occluded by the inducers, whereas texture elements inside the illusory surface appear to be above the inducers. They demonstrated that, when texture elements are also placed in front of the inducers (i.e., occlusion information at monocular level are disambiguated), *all* of them are pulled forward on the same depth plane specified by vertical disparities (ibid., fig. 4, p. 2895).

Our results suggested that ambiguous information at the monocular level is sufficient to give rise to a capture effect, and that vertical disparity information just make the effect more visible.

In the past, it has been shown that size constancy mechanisms are activated by the apparent depth in illusory surfaces (Coren, 1972; Coren & Porac, 1983): if two dots of the same size are placed on two surfaces (the illusory surface and the background) that are registered to be on different depth levels, the dot placed on the closest surface will appear smaller than the other. This depth effect was also registered using a three-level illusory

configuration (Purghé & Coren, 1992b; Salzman & Halpern, 1982), demonstrating that the visual system represents 2D figures as objects in a 3D space (Qui & von der Heydt, 2005). Our results are in agreement with these observations: when texture elements (but also single elements: see Bertamini, Bruno, & Mosca, 2004) are presented within the illusory surface, they are “pushed” on a depth plane that is on top of the illusory surface, which is perceived as an opaque occluder. On the other hand, with homogeneous configurations the additional depth plane on which the elements are lying disappears.

Since our stimuli are very similar to the ones used by other authors, we think it is worth discussing their findings. Van Lier et al. (2006) have proposed an interpretation based on perceptual transparency as previously discussed by Purghé (1998): the illusory surfaces in heterogeneous contexts acquire a transparent propriety, as a sort of lens or piece of glass glued onto the edges of the inducers’ indentations. This interpretation is based on the claim that heterogeneous configurations should bring contrary evidence to occlusion, because the presence of the illusory surface does not prevent the observer from seeing what should be hidden behind it. Our results may contradict such a proposal: depth stratification enhancement suggests that the elements inside the illusory surface are not perceived behind it, but above it, closer to the observer. If this is indeed the case, it would seem difficult for the lens hypothesis to explain why the elements inside the illusory surface are perceived as lying on top of the lens (ibid, p 339). On the other hand, we tested the stratification of the illusory surface, and did not measure directly depth stratification of background elements. In principle, it could be that these elements appear closer than the rest of the background, and yet behind the illusory figure, which is perceived as transparent.

In the present work, we investigated the aspect of illusory contour figures that has received less attention, showing that depth stratification is independent from illusory contour clarity and brightness enhancement. Ours was the first attempt to measure depth stratification in heterogeneous contexts.

2. An indirect measurement of depth stratification in illusory contour figures

2.1 Introduction

This study was designed to measure apparent depth stratification in heterogeneous contexts shown in figures 1.2 by employing a size constancy manipulation, such as that proposed by Coren (1972) and Porac (1978). Their procedure consisted in placing two targets of the same physical size, one on the illusory figure and the other on the background: participants were asked to judge the apparent size of these targets. The authors' main assumption was that, if the surface that a target rested upon was registered as being more distant, then size constancy scaling should be triggered, and it should appear to be larger than a target on a surface registered as being closer. This procedure thus evaluate apparent depth without requiring a direct assessment.

This indirect method has been employed for measuring depth stratification in illusory figures exclusively in homogeneous contexts, i.e., with inducers depicted against uniform white backgrounds (see also: Salzman & Halpern, 1982; Coren & Porac, 1983, Coren, Porac, & Theodor, 1986; Parks, 1987; Purgé & Coren, 1992b). In this study, we asked ourselves whether this method is suitable for measurements in heterogeneous contexts.

2.2 Methods

Participants. A total of 16 (10 females, mean age 25; range 22 - 29) participants took part in this experiment. To prevent fatigue effects, 8 participated in the “illusory figure condition”, while the others participated in the “control condition”. All observers were undergraduate students, naïve as to the purpose of the study, and had normal or corrected-to-normal vision. All participants gave written informed consent.

Apparatus and Stimuli. The stimuli were created on a Pentium IV personal computer using

Adobe Photoshop 6.0. The program ERTS (Experimental Run-Time System, Berisoft, Frankfurt, Germany) was employed to control stimuli presentation and to record observers' responses. Participants observed the PC screen with binocular view from a distance of 80 cm. Response keys were located on a dedicated response-box. The experiments were performed in a dimly lit, sound-shielded room.

Stimuli were full screen images with a size of 1024x768 pixels presented through a PC on a 17-in. colour monitor (refresh rate, 60 Hz) with a standard resolution of 72 pixels per inch (28.3 pixels per cm). At the viewing distance of 80 cm, the images subtended 25.91 x 19.43 degrees of visual angle.

Four different displays were built and employed in the experiment by varying the illusory figure (present or absent) and the background (homogeneous or textured). Standard and test stimuli (two red dots) were superimposed on these four displays. In the following paragraphs, stimuli description is presented.

Illusory figures. In the illusory contour condition, the inducers were four black pacmen (luminance value: 2 cd/m²), placed at the centre of the screen, subtending an illusory square region of 120 x 120 pixels (horizontal and vertical visual angles of 3.04 deg). Each of the four pacmen had a diameter of 80 pixels (2.03 deg), therefore a radius of 40 pixels (1.013 deg). The support ratio - the ratio between the luminance-defined portion and the entire bounding contour (Shipley & Kellman, 1992b), was maintained fixed with a value of 0.67: that is, the distance between the centres of any two consecutive inducers always measured three times the radius of the inducers themselves.

In the control condition, each of the four pacmen was rotated by 180° on its centre, creating no illusory figure at all.

Backgrounds. Two backgrounds were employed: one homogeneous grey and one heterogeneous textured Gaussian-noise. The sides of the monochromatic square checks within the texture measured 4 pixels (at an observation distance of 80 cm: 0.1 deg of visual angle). The distribution of luminance values between black and white was represented by a histogram with a Gaussian distribution (Chubb et al., 1994). Mean luminance value of both backgrounds was 40 cd/m².

Standard and test stimuli. Two red dots have been superimposed on these four displays: one inside the illusory figure and the other on the background, as illustrated in figure

2.1. The dot placed on the illusory square was always of the same size (16 pixels corresponding to 0.4 deg) while the dot placed on the background could vary its size across 5 levels (from 14 to 18 pixels, corresponding to 0.35, 0.38, 0.40, 0.43, and 0.46 deg). The location of the dots was maintained constant: their centres corresponded to the intersection between the horizontal midline of the illusory figure and the two vertical lines that bisected the horizontal radii of the two inducers placed on the right side of the configuration.

A total of 20 displays were built: 2 (illusory figure present or absent) x 2 (homogeneous or textured background) x 5 (different test dot diameter size).

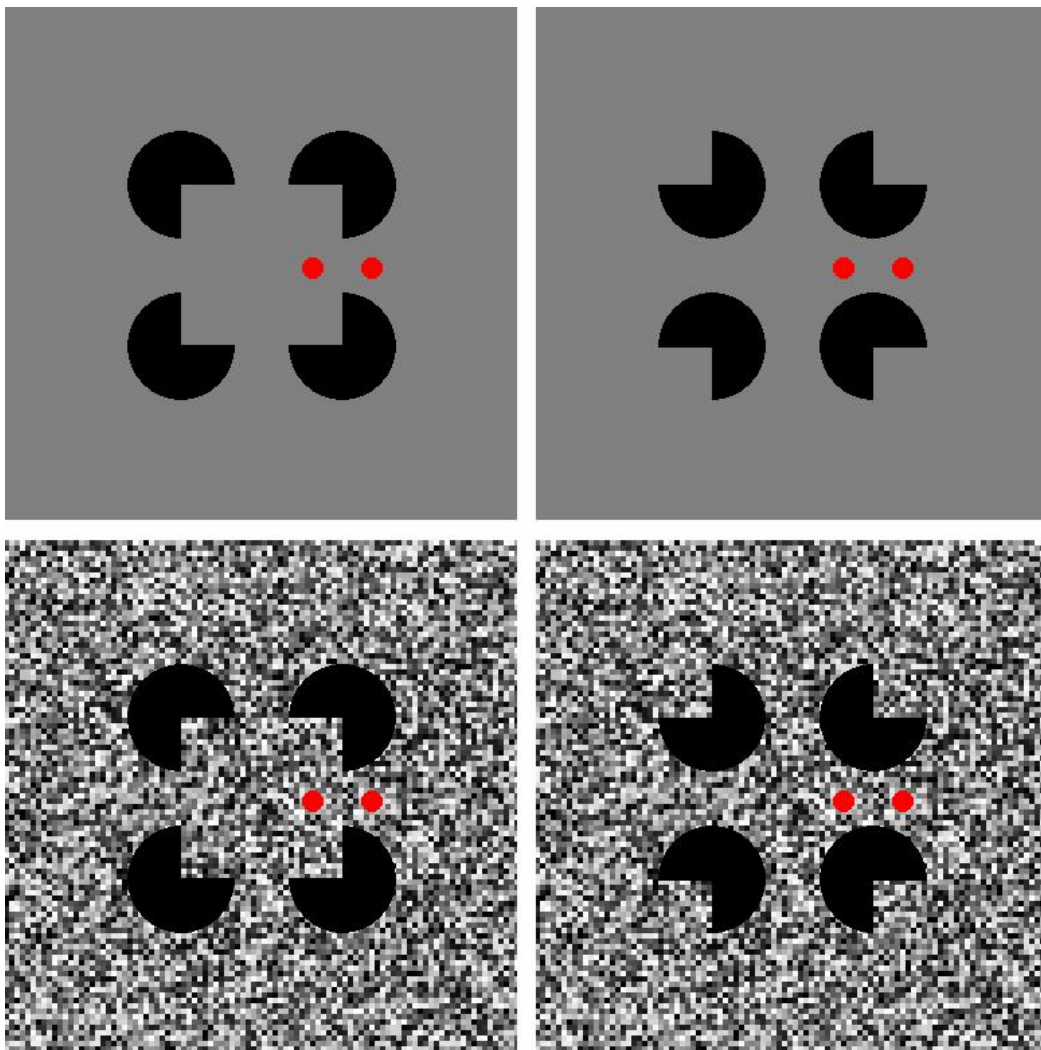


Fig. 2.1. Examples of stimuli employed to measure depth stratification. In homogeneous contexts (above), apparent depth stratification has been measured indirectly, by placing one target dot upon and the other outside the illusory figure. Since the illusory figure is perceived

as being closer to the observer, the two dots appear as lying on different depth planes: the dot on the left is captured by the illusory square and pulled nearer to the observer. This apparent depth difference is able to activate size constancy mechanisms: the farther dot appears larger, although the two are of the same size. In the control condition (right), no illusory surface is perceived, thus apparent size should not be affected.

In heterogeneous contexts (below), a textured background is placed behind the elements.

Procedure. Method of Constant Stimuli was used to measure the perceived size of two dots and to obtain complete psychometric functions.

Each participant began by sitting comfortably in front of the PC monitor and reading the task instructions, presented in written form on a sheet of paper. After that, the experimenter asked them if the instructions were clear. Should the answer to this question be negative, further explanations would be forthcoming, until complete understanding of the delivery. Observing distance was measured and if necessary the position of the seat was adjusted so to ensure a constant value of 80 centimetres from the PC screen.

To reduce fatigue effects, half of the observers participated in the illusory figure condition, while the other half participated in the control condition. Each condition consisted in a block of 400 trials: 40 repetitions of 10 stimuli (2 x 5: homogeneous or textured background x different dot sizes). Thus each condition lasted approximately 15 minutes. Trials presentation was randomized in a standard computer assisted way. No practice session was present.

The sequence of events in a single trial was as follows. Each trial began with a fixation signal presented slightly to the right of the centre of the screen (a white cross drawn on a black background): this position corresponded to the midpoint between the two red dots. After 500 milliseconds, the fixation cross was replaced by the stimulus image for a period of 1 second. Then a black screen was presented for 500 milliseconds, allowing participants to give a response through the two-buttons dedicated response box. Between consecutive trials, a random time interval between 100 and 500 milliseconds was inserted. Participants were asked to answer the following question: “Is the larger (or smaller) red dot on the right or on the left side between the two?”, thus performing a two-alternative forced choice task. If the dot on the right (left) appeared bigger than the one on the left (right), participants had to press the right (left) button with the middle (index) finger of their dominant hand. The delivery question was balanced: half of the participants were asked for the larger dot, the other half for the smaller dot. Participants were instructed to respond as quickly as possible, but only when the stimulus

display disappeared, because response latency (RT) was recorded, and also to minimize the number of errors.

Data Analysis. The trials for each observer were grouped into four conditions, depending on the context in which the size discrimination task was performed: i) with the illusory figure on homogeneous grey background (IC – H), ii) with the illusory figure on heterogeneous textured background (IC – T), iii) without illusory figure on homogeneous grey background (C – H), iv) without illusory figure on heterogeneous textured background (C – T).

For each observer, the proportion of trials in which s/he judged the test stimulus has been determined as the larger stimulus as a function of the test size. This corresponded to the proportion of times the answer “the bigger dot of the two is on the right side” was given. These values were fitted with the following logistic function:

where p_c is the probability to respond “bigger dot on the right” when observing the test stimulus size x , p_{\min} and p_{\max} are respectively the lower and upper limits of the function; k represents its slope, and m is its midpoint, which corresponds to abscissa value where the change in curvature of the function takes place. Since logistic functions are symmetrical about the vertical line, and the range of the function is between zero and one, the curvature change occurs at $p_c = 0.50$.

The quality of the resulting fit was quantified by calculating the correlation coefficient of the logistic regression between the raw and the predicted response probability for the 5 stimulus levels tested. Obtained values were: $R^2 \geq .906$, confirming that a logistic function well represents these data.

Three parameters were calculated for each observer after the fitting procedure and subsequently used to compare the shape and displacement of the psychometric functions: the slope of the psychometric function, the point of subjective equality, and the differential threshold. Mean reaction times were also considered in the analysis.

Slope. Sensitivity is reflected in the slope of the psychometric function. A relatively steep slope means that with small changes in the physical size of the test stimulus (here expressed either as pixels or as a ratio, as discussed above), the participant's average responses quickly switch from "0" to "1". In other words, the participant notices even small changes. In contrast, a relatively flat curve indicates that a participant has more difficulties with the task.

Point of subjective equality. In the present experiment, the point of subjective equality (PSE) corresponds to the test dot's size value which makes it appear of the same size as the standard dot. More specifically, the size value of the test dot associated with a probability to respond either "bigger dot on the right" or "bigger dot on the left" with the same probability. This corresponds to a response "bigger dot on the right" with a probability of .5. This makes the PSE to correspond to the logarithmic function's midpoint.

It is also possible to express the test stimulus size (the value represented on the x-axis) as a ratio between the size of the test dot and the size of the standard dot. Under this condition, a PSE value larger than 1 in this experimental design indicates that the size of the test stimulus had to be larger than the standard stimulus size in order to be perceived as of the same size. A PSE below 1 indicates that the size of the test stimulus had to be smaller than the standard stimulus size. If PSE equals 1, the two dots are perceived as of the same size when they have the same physical size; in other words, the PSE corresponds to the point of physical equality (PPE).

Differential threshold. The differential threshold (DL) is a measure of the minimum difference of intensity between two stimuli that is necessary in order for the difference to be reliably perceived. In the present experiment, the DL corresponds to the minimum increment in size of the test dot in order for it to be perceived as different from the standard dot by the observers.

Mean reaction times. Another index has been considered in the analysis: differential mean reaction times. This reflects the time employed by observers to respond to the question "Is the larger red dot on the right or on the left side?". Generally, differences in reaction time between experimental conditions are due to different processing time required.

To test whether mean PSE values relative to each of the four groups were significantly different from the point of physical equality (PPE), one-sample Student's t-test was used.

To test the effects on PSE, slope and on DL of the illusory figure (present vs absent; *between subjects* factor) and the background (homogeneous and textured; *within subjects* factor), a mixed repeated measures ANOVA was used. To test the same effects on mean reaction time, a three-way mixed repeated measure ANOVA was employed. Post-hoc comparisons with Student's t-test with Bonferroni correction were applied. Data analysis was carried out with SPSS 13.0 for Windows (SPSS Inc., Chicago, IL, 2004) and Microsoft Excel 2003 was used to plot graphs.

2.3 Results

The slope, PSE, and DL values were compared with a mixed repeated measures ANOVA, with a between-subjects two-level factor (*illusory figure*: present vs absent) and a within-subjects two-level factor (*background*: homogeneous vs textured). Mean reaction times (mRTs) were compared with a mixed repeated measure ANOVA, with a two-level between-subjects factor (*illusory figure*: present vs absent), a two-level within-subjects factor (*background*: homogeneous vs textured), and a five-level within-subjects factor (*test dot size*: from 14 to 18 pixels). Illusory figure and background manipulations had no effect on slope or DL, However, a significant main effect of the background factor on PSE was found ($F_{(1,14)} = 17.228$, $p = .001$). The mean PSE for the homogeneous and textured background were respectively 16.12 and 15.94 pixels (0.408 and 0.403 degrees of visual angle), corresponding to a ratio between the size of the test dot and the size of the standard dot of 1.01 and 1, respectively. Moreover, a significant interaction between illusory figure and background factors was found ($F_{(1,14)} = 7.389$, $p = .017$). It is to note that none of the PSE values were statistically different from the size of the standard stimulus (one sample Student's t-test, $p > 0.05$). PSE values are presented in table 2.1 and 2.2.

Group PSE (deg.)	Homogeneous Background	Textured Background	Tot
Illusory Figure present	0.406	0,404	0.405
Illusory Figure absent	0.410	0,402	0.406
Tot	0.408	0.403	

Table. 2.1. Point of subjective equality expressed in degrees of visual angle.

Group PSE (PSE/Std.Stim.)	Homogeneous Background	Textured Background	Tot
Illusory Figure present	1.00	1.00	1.00

Illusory Figure absent	1.01	0.99	1.00
<i>Tot</i>	<i>1.01</i>	<i>1.00</i>	

Table 2.2. Point of subjective equality expressed as the ratio between the size of the test stimulus and the size of the standard stimulus.

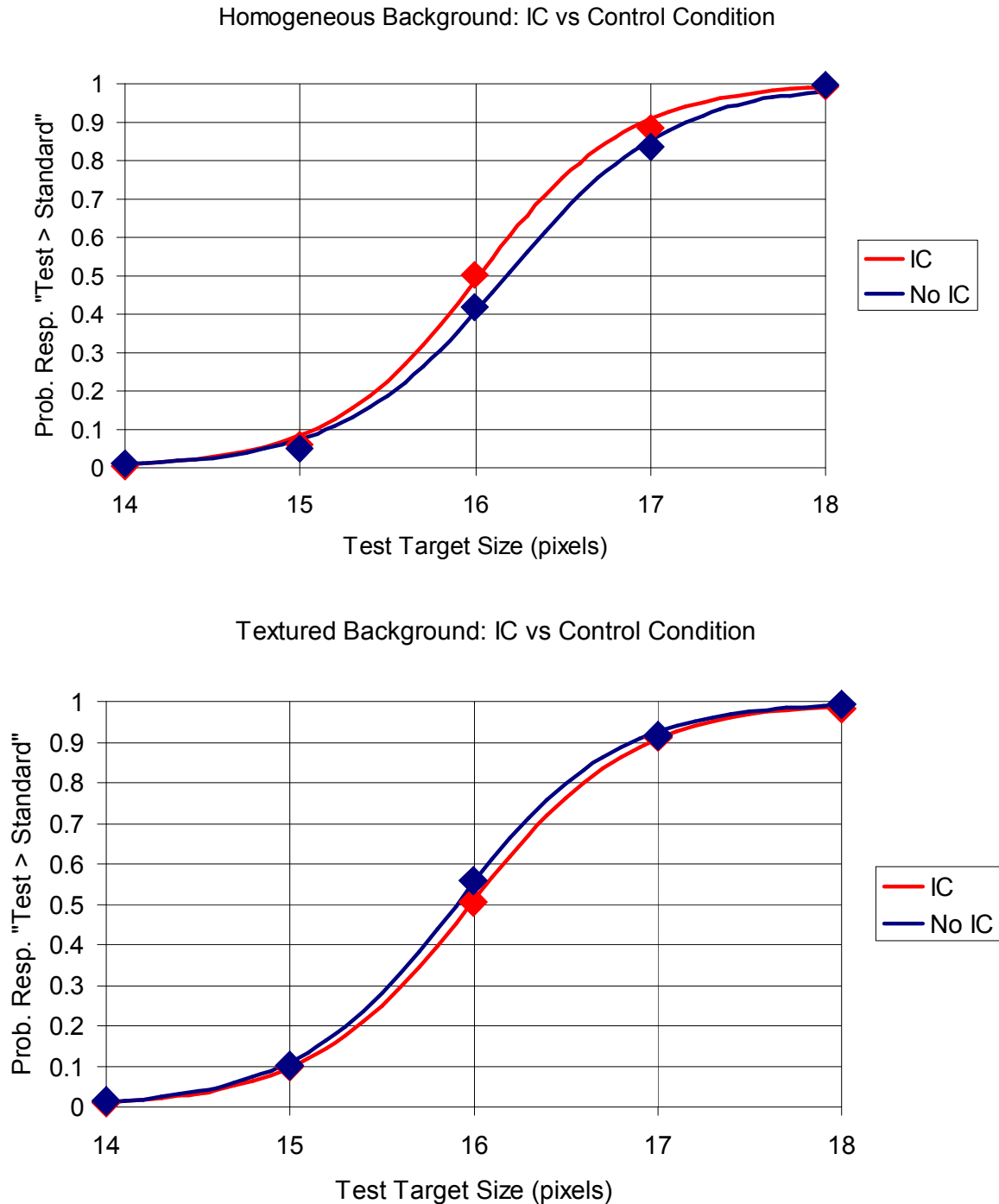


Fig. 2.2. Psychometric functions relative to the four experimental conditions. Proportion of responses in which observers reported the size of the test stimulus as larger than the standard stimulus, plotted as a function of the test dot physical size in pixels: corresponding visual angle values were 0.35, 0.38, 0.40, 0.43, 0.46 deg., respectively. Data are shown for the illusory contour figure condition (IC, red line) and for the control condition (No IC, blue line). The standard dot always measured 16 pixels (0.40 deg). Horizontal lines intersecting the curves at a value of .5 indicate the size necessary for the test and standard stimuli to attain a

subjective equality. In homogeneous conditions (above), in respect to the control condition, a underestimation of the target stimulus was present (or, conversely, an overestimation of the standard stimulus). However, with textured background no differences were found.

Main effects on mean reaction times of test stimulus size ($F_{(4,56)} = 12.109, p = .0001$) and illusory figure factors ($F_{(1,14)} = 5.053, p = .041$) were found. The first result suggested the presence of a distance effect (objects close in physical size are more difficult to compare than objects very different in size). The second result indicated that, when an illusory contoured figure is present, observers' mean reaction times are longer for a mean value of 85 milliseconds.

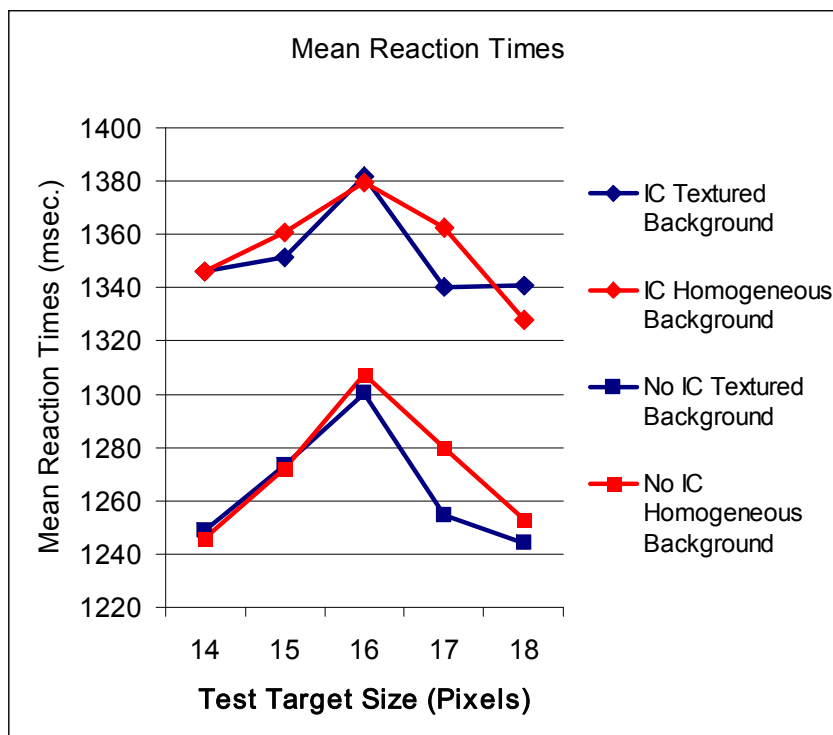


Fig. 2.3. Mean reaction times relative to the four experimental conditions. A distance effect is present when considering all conditions together: objects close in physical size are more difficult to compare than objects very different in size. Moreover, regardless the type of background and test target size, a difference between mean reaction time relative to illusory figure and control conditions was found. Test target size in degrees of visual angle were 0.35, 0.38, 0.40, 0.43, 0.46 deg., respectively.

2.4 General Discussion

This study was run to quantify apparent depth stratification in illusory contour figures depicted against homogeneous and heterogeneous contexts. A method proposed by Coren (1972) and Porac (1978), and used later by Salzman & Halpern (1982), Coren & Porac (1983), Coren et al. (1986), Parks (1987), and Pughé & Coren (1992b), has been employed here for the first time considering not only homogeneous, but also heterogeneous backgrounds.

This method involves an indirect measure of depth: it has been shown that stimuli placed on and beside illusory figures in homogeneous contexts are able to activate size constancy mechanisms.

In this experiment, the slope of the psychometric functions can be interpreted as a measure of ability to discriminate between the size of the standard and test dots. Since no significant differences were found, it is possible to conclude that observers' sensitivity is not affected by an illusory figure or a textured background. On the other hand, the point of subjective equality (PSE) was affected by the experimental manipulations.

Regardless of the presence or absence of an illusory figure, it was found that with a grey homogeneous background, observers overestimated the size of the test dot. But when the discrimination task was performed against a heterogeneous background, observers were found to be accurate.

A second result pointed out an interaction between presence or absence of the illusory figure and types of background employed. On homogeneous backgrounds, a shift of PSE values has been found in the expected direction (Coren, 1972; Coren & Porac, 1983): when the illusory figure was present, observers perceived the test target as smaller if compared to the control condition. This result has been explained by the displacement in depth produced by illusory contour configurations and the subsequent action of size constancy mechanisms. In particular, the target placed on the illusory figure is perceived as closer to the observer, whereas the test target, placed beside the illusory figure, is perceived as lying on a more distant plane. Size constancy mechanisms produce a size overestimation of the more distant target that in turn gave rise to underestimations in the size discrimination task. However, when the homogeneous background was substituted by a heterogeneous, textured background, the effect unexpectedly disappeared.

In our opinion, performance was uniformly enhanced by heterogeneous contexts because of positional cues within the texture that observers may have taken advantage of (see Aks & Enns, 1996). At an observation distance of 80 cm, real luminance edges inside the textures could have worked as a reference system for the discrimination task (e.g., as a ruler).

Observers were also found to be more accurate on heterogeneous backgrounds in comparison to homogeneous backgrounds, regardless of the presence of an illusory contour configuration. This second result strongly supports our claim.

Not surprisingly, mean reaction times analysis showed the presence of a distance effect: objects close in physical size are more difficult to compare than objects very different in size. The unexpected result regarded the fact that longer reaction times were recorded when an illusory contoured figure was present. In this case, observers' performance was slower by a mean value of 85 milliseconds. Since other indexes did not yield differences in the ability to discriminate between the two dots, it seemed reasonable to exclude that this result was produced by an increment in the difficulty of the task. The time difference we found may be attributed to the processing of depth perceived in illusory contours configuration (Parlangeli, Guidi, & Palmer, 2007). However, since the result regards two different groups of participants, we felt cautious in drawing conclusions and recommend at least a replication of the effect with more subjects before further speculation.

3. The Illusory Contoured Tilting Pyramid

The employment of heterogeneous backgrounds with illusory contour configurations can give rise to particularly striking illusions. Here we present a new illusion, called “The Illusory Contoured Tilting Pyramid”. This illusion was entered in the international contest “Best Visual Illusion of the Year Contest”, held in Sarasota in May 2007, where it obtained an excellent reception and was voted as the second best illusion.

3.1 Description of the visual illusion

A modified Kanizsa triangle has been superimposed on a heterogeneous background in which three regions with different luminance converge in a common point. The result of this procedure gave rise to a solid, illusory contoured object: observers reported they perceived a triangular-based solid pyramid floating over three black disks (fig. 3.1). The surfaces on the background are often reported as the corner of a room, thus, a concave perceptual solution in opposition to the convex nature of the pyramid.

It is to note that the background here considered can be seen as two alternative percepts: either 1) as a set of three flat geometric shapes lying on the same depth plane or 2) as the isometric projection of the vertex of a solid shape (e.g. a cube). It is widely known that the lack of depth cues in this type of projection system may produce perceptual ambiguity (Necker, 1832): it is possible to perceive either a concave or a convex vertex. When pacmen inducers are superimposed on this background, the bistability of the inner region (the pyramid) is prevented due to the emergence of the illusory solid shape.

One animated background was built, in which the magnitude and height of the vertex were continuously changed, while the points of intersection between inducers and edges were maintained fixed (the centres of rotation correspond to the centres of the inducers). The resulting animation elicits the vivid perception of a solid triangular-based pyramid rotating back and forth along its longitudinal axis, preventing the concave-vertex percept. When the superimposed inducers are not aligned or absent, the concavity / convexity bistability is restored, due to lack of illusory contoured figure formation.

As well as the IC contoured solid object, another illusory percept arises: observers spontaneously reported they perceived a change in brightness on the faces of the pyramid,

when compared to the surfaces on the background, although there were no differences in the stimulus. This aspect, taken together with the appearance of illusory contours (the edges of the pyramid) and depth stratification (the pyramid is perceived as floating on the disks), completes the set of defining features of illusory contour figures, and also extends them to illusory solid objects.

To support with experimental results these observations, two experiments were designed and run to assess the causal role of illusory contours on the formation of the illusory pyramid, giving experimental evidence to observers' reports: in Experiment 1, we measured the brightness enhancement on the faces of the pyramid using the method of adjustments; in Experiment 2, we test whether the illusory contoured solid object could also be seen without alignment between background and pacmen inducers, and when illusory contour formation is hampered by real luminance edges.

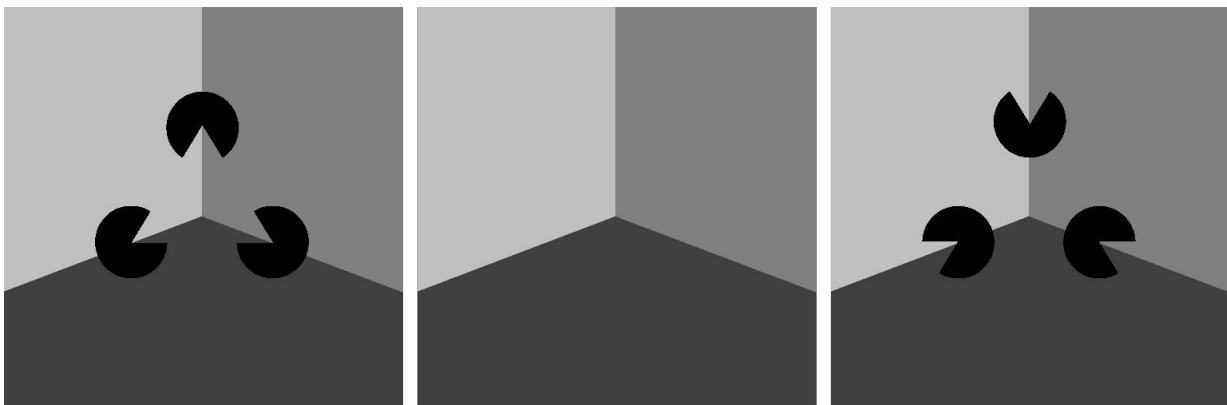


Fig. 3.1. The illusory contoured *static* pyramid (left). Pacmen inducers have been superimposed on a heterogeneous background in which three regions with different luminance converge in a common point (centre): observers reported they perceived a triangular-based solid pyramid floating over three black disks. When inducers were misaligned, no pyramid was perceived.

3.2 Experiment 1: Brightness Enhancement

The aim of this experiment was to document the brightness enhancement on the faces of the illusory contoured pyramid, which was spontaneously reported by observers. Participants were shown picture stills taken from the animation described above, depicting

backgrounds with different angles. Then, they were asked to adjust the brightness of a corresponding panel without inducers, until they matched it with the perceived brightness of the pyramid's face. Each participant made brightness adjustments for the two vertical faces of the pyramid (the third face of the pyramid, frequently reported to be perceived as the base, was excluded since throughout the animation it disappeared), in configurations with and without inducers.

3.2.1 Methods

Participants. A total of 10 subjects aged 22 to 36 (mean age 27), 6 males and 4 females, participated in the experiment. All subjects were students of the Department of Psychology at Padua University and were naïve regarding the purpose of the experiment. All had normal or corrected-to-normal vision.

Stimuli and Apparatus. A total of 16 target stimuli were employed: 8 stimuli were collected by taking picture stills from the animation described above, depicting pacmen inducers on backgrounds with different angles between the three regions (i.e., different orientation of the pyramid, during tilting). Other 8 stimuli were built for the control condition, by removing pacmen inducers from the previous stimuli (fig. 3.2). All 16 stimuli were saved in bitmap format.

Mean luminance values for the background regions were: left region, 28.71 cd/m², right region, 11.49 cd/m², and lower region, 2.84 cd/m². Black inducers brightness measured 1.37 cd/m².

Test stimuli were identical to inducer-less target stimuli, but with a region (either left or right) with adjustable brightness: by moving a joystick slider up or down, it was possible to increment or decrease it. Two buttons were dedicated to finer adjustments with a step of 1 within the 0-255 range of RGB values.

Target and test stimuli were embedded in an HTML white page without borders with a size of 1280x1024 pixels, and displayed on a 19-inch NEC CRT personal computer monitor (model: MultiSync 95F) with standard resolution of 72 pixels per inch (28.3 pixels per cm), placed horizontally at the same distance from the centre of the screen (fig. 3.3), and connected to a Pentium Core Duo 2 personal computer. Refresh rate of the monitor was 85 Hz. Stimuli

measured 300 x 300 pixels, thus subtending a region of 8.68 x 8.68 degrees of visual angle at the observation distance of 70 centimetres.

Target stimuli were bitmap images built using Photoshop 6.0 by Adobe. Test stimuli were compiled using Virtools 3.5 by Dassault Systèmes (2005).

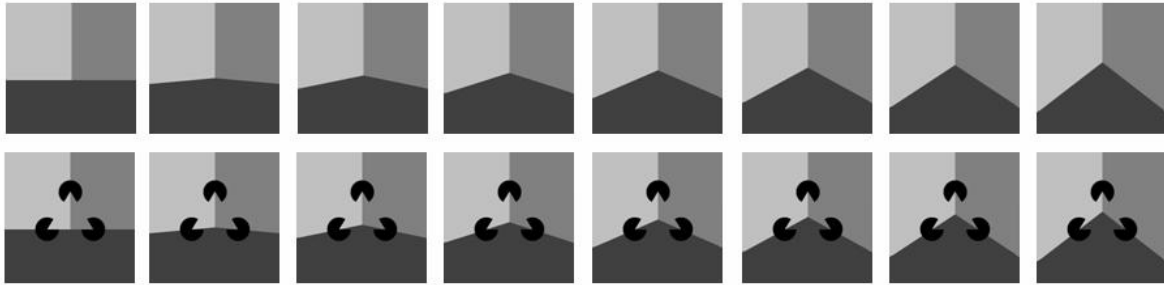


Fig. 3.2. Stimuli employed in Experiment 1. The patterns reproduced eight different frames of the illusory pyramid tilting animation: from left to right, the pyramid tilts backward. Target stimuli (below) reproduced inducers superimposed on the corresponding test stimuli (above). The brightness of the left and right regions in the test stimuli was controlled by a joystick slider.

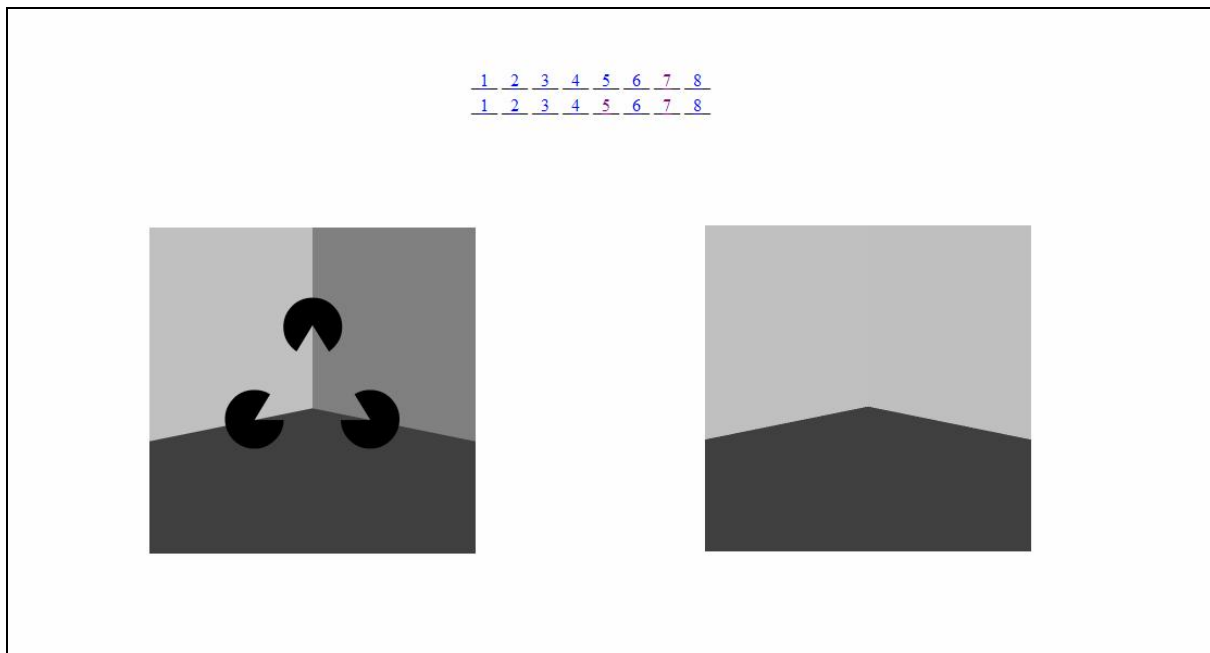


Fig. 3.3. Setting of experiment 1. Participants viewed on the same screen a target stimulus (left) and the corresponding test stimulus (right). They were asked to adjust the brightness of one side of the test panel (separately, left and right), until they matched the brightness of the corresponding region of the target stimulus. In this figure, participants had to match the brightness of the right pyramid's face with the right panel of the test stimulus. This description corresponded to the test condition: in the control condition, no inducers were present in the target stimuli.

Procedure. Each participant began by comfortably sitting in front of the PC monitor, and was randomly assigned to start with the test or control condition.

In the test condition, each participant was shown the stimulus depicted in figure 3.1 and invited to describe it. The experimenter wrote down the description paying particular attention to assess: 1) whether the illusory pyramid was perceived, 2) whether the brightness enhancement on the pyramid faces was perceived, 3) whether illusory contours were perceived. Should the answer to one of these questions be negative, the participant completed the task anyhow. After this first assessment, participants were asked to adjust the brightness of one region in the test stimulus to match the brightness of the corresponding region in the target stimulus. Demonstrations on how the joystick slider and buttons operated were also given. After complete understanding of the delivery, the experimental session started. Each participant observed 8 stimuli, and made 16 adjustments (one for each of the two vertical pyramid's faces).

In the control condition, participants were invited to adjust the brightness of one specified region of the three-part background to match the corresponding region of an identical target stimulus. In the control stimuli, no inducers were present. After demonstrations on how the joystick slider and buttons operated, the experimental session began. Each participant observed 8 stimuli, and made 16 adjustments (one for each of the two vertical pyramid's faces).

After the experimental sessions, participants were shown the animation described in the introduction (the tilting pyramid) and asked to describe it, confirming or eventually modifying the impressions reported at the beginning of the experiment. Particular attention was paid to assess whether a change in brightness was perceived during tilting. Adjustment data were automatically recorded and saved in separate text files.

Subjects viewed the stimuli with both eyes at an observation distance of 70 cm. All observations were carried out in a dimly lit room.

3.2.2 Results

Reports. All ten participants reported they perceived a solid triangular-based pyramid with its tip pointing upwards. The pyramid was described as “coming out from the centre of the screen”, and “in front of three black circles”; the background was frequently described as a concave corner of a room (“going inside the screen”). Only one subject reported an additional

alternative percept: “a transparent flat triangle placed on three disks in front of a concave corner of a room”.

All participants except one reported they perceived the pyramid’s illusory contours. In this case, the pyramid was clearly perceived, but without illusory borders.

Brightness enhancement was reported by 8 out of 10 observers, although some observers thought it more appropriate to call it a “change” of brightness. The left pyramid face was perceived always as brighter than the background; the face on the right was perceived sometimes as brighter (4 observers) and sometimes as darker (3 observers). However, the change was reported always as weaker in comparison to the left face. The lower face was perceived as either brighter (2 observers) or darker (3 observers) than the background.

During the adjustment sessions, some observer spontaneously reported that “the task is particularly difficult, because I can’t find the right shade of grey”, “the surface quality that changes when the pyramid is present seems not to be the one I am manipulating”.

Brightness Adjustment. A repeated measure analysis of variance was performed, considering the Pyramid Faces (2 levels: right / left), Condition (2 levels: with / without pacmen inducers), and Angle (8 levels: the different magnitudes of the angle formed by the three regions in the background) as within factors. Since no difference were found between different angle positions, data regarding this factor were pooled together and further analysis was carried out using paired Student t-test.

Results showed a clear brightness enhancement effect: observers rated both faces as 2.5% brighter when pacmen inducers were present rather than absent (left face: $t = 3.727$, $d.f. = 9$, $p = .005$; brightness: w. inducers = 53.6%, w/out inducers = 51.1%; right face: $t = 4.792$, $d.f. = 9$, $p = .001$; brightness: w. inducers = 78.1%, w/out inducers = 75.6%). Results are discussed in the general discussion section.

3.3. Experiment 2: Illusory Pyramid Degradation

In this experiment, we tested whether the illusory pyramid could be seen without the alignment between real luminance edges within the background and the inducers. The illusion was parametrically degraded by rotating the background around its centre. At one specific

point during this rotation, real luminance edges within the background crossed the illusory contours, interfering with their formation.

3.3.1. Methods

Participants. A total of 8 subjects aged 22 to 35 (mean age 29), 6 males and 2 females, participated in the experiment. All subjects were students of the Department of Psychology at Padua University and were naïve regarding the purpose of the experiment. All had normal or corrected-to-normal vision.

Stimuli and Apparatus. A total of 13 stimuli were build from the original illusory pyramid stimulus by rotating the three-part background around its centre from 0° to 24° in 2° steps. Each image had a size of 579 x 579 pixels (16.75 x 16.75 deg.), and was displayed on a 19 inch. NEC CRT monitor (model: MultiSync 95F) with a desktop size of 1280 x 1024 pixels, and standard resolution of 72 pixels per inch (28.3 pixels per cm). Refresh rate of the monitor was 85 Hz. Photoshop 6.0 by Adobe was used to produce the stimuli. E-Prime software version 1.1 (Psychology Software Tools, 2001) running on a Pentium Core Duo 2 personal computer was employed to control stimuli presentation and to record subject responses.

Mean luminance values for the background regions were: left region, 27.54 cd/m², right region, 10.98 cd/m², and lower region, 2.94 cd/m². Black inducers brightness measured 1.37 cd/m².

Procedure. Each participant began by comfortably sitting in front of the PC monitor, examining and describing the illusory pyramid static configuration (fig.3.1). Only participants that clearly perceived the pyramid were allowed to continue. They were instructed to press a key (“1”) if they saw a solid object coming out from the region inside the inducers, or press another key (“2”) if flat surfaces were perceived. The question regarded a generally specified “solid object” because background manipulation could produce distortions: to keep observers from giving positive answers only to the regular pyramid, we preferred this formulation of the delivery. Each of the 13 stimuli was presented 25 times in a randomized order. Each stimulus was presented for 500 msec. Response data were automatically recorded and saved in separate text files.

Subjects viewed the stimuli with both eyes at an observation distance of 70 cm. All observations were carried out in a dimly lit room.

Data Analysis and Results. For each observer, the proportion of responses in which s/he perceived a solid object has been determined. These values were fitted with the following logistic function:

where p_c is the probability of the response “yes, I perceived a solid object” when observing the stimulus with a background rotated by an angle of x degrees; p_{\min} and p_{\max} are respectively the lower and upper limits of the function; k represents its slope, and m is its midpoint, which corresponds to the abscissa value where the change in curvature of the function takes place. Since logistic functions are symmetrical around the point of inflection, and the range of the function is between zero and one, the curvature change occurs at $p_c = 0.50$.

The quality of the resulting fit was quantified by calculating the correlation coefficient of the logistic regression between raw and predicted response probability for the 13 levels tested. The values obtained were: $R^2 \geq .942$, confirming that a logistic function well represents these data.

A psychometric function relative to the mean values of “yes, I perceived a solid object” response probabilities was also fitted and plotted, representing group performance (fig. 3.4).

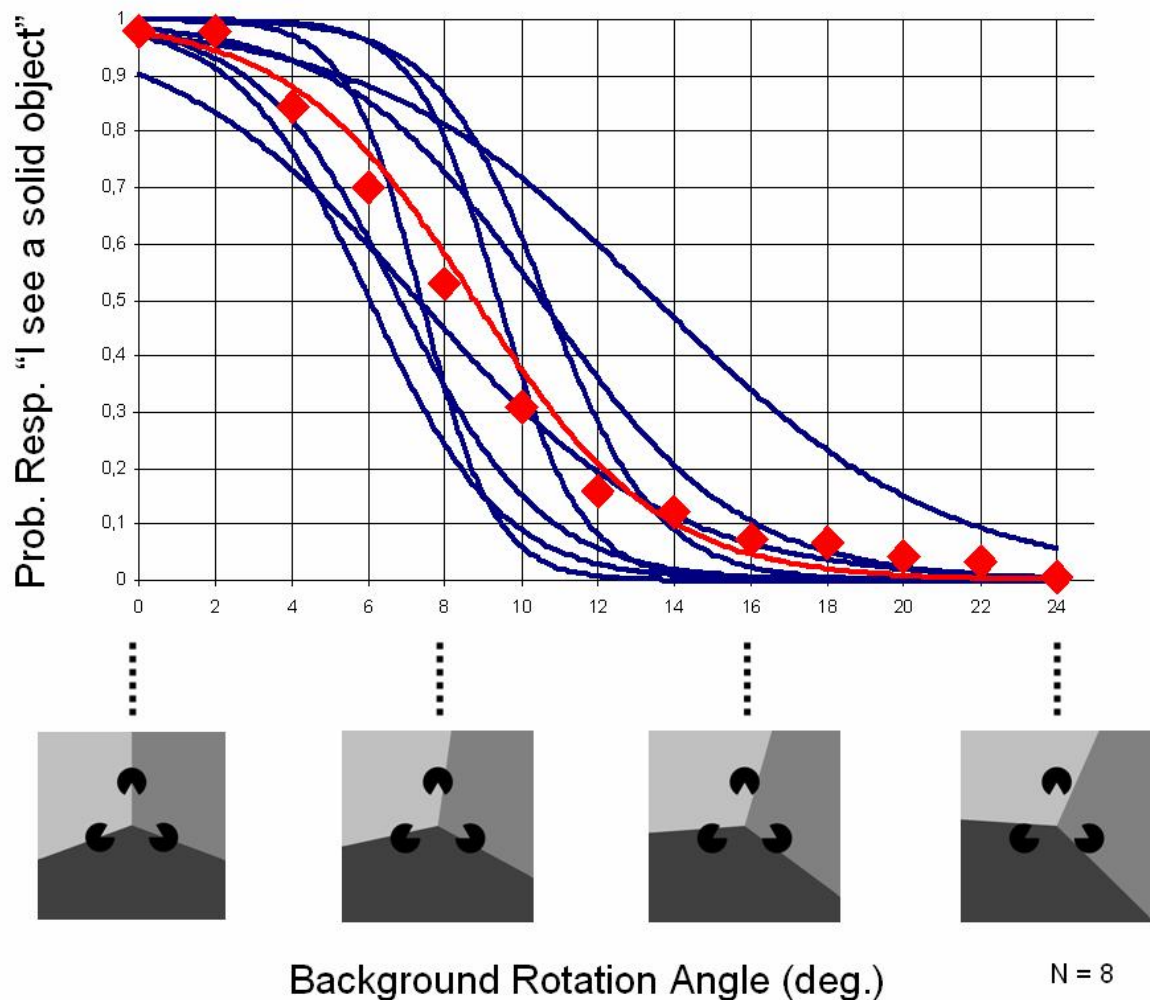


Fig. 3.4. Psychometric functions relative to the 8 participants (blue) and relative to group mean values (red). Proportion of responses in which observers reported to perceive a solid object coming out from the region inside the inducers, plotted as a function of the background rotation angle.

3.4 General Discussion

In the first experiment, we measured the brightness enhancement on the vertical faces of the illusory pyramid. Participants were asked to adjust the brightness of a test panel, until they matched its brightness with the perceived brightness of 1) the pyramid's faces and 2) an identical inducer-less pattern. Results showed a clear brightness enhancement effect: observers rated both faces as 2.5% brighter when the pyramid is present.

It is widely known that illusory contour figures produce a brightness enhancement effect (Kanizsa, 1955) and that illusory figures appear brighter than they should if conventional brightness contrast alone were responsible for the effect (Bradley & Mates, 1985; Coren & Theodeor, 1975; Dresch, 1992). Our results supported the evidence that an illusory brightness is also present in illusory solid objects.

Some observers also reported a change in brightness enhancement while looking at the animation: when the pyramid is perceived as lying on the horizontal plane (the lower face is hidden), the two sides are perceived as brighter. However, this observation was not supported by the data gathered in the experiments. Further investigations are necessary to assess whether this effect is connected to dynamic changes in the animated stimulus.

In the second experiment, we tested whether alignment and illusory contours are necessary to perceive the illusory pyramid. By using a yes/no task, eight participants were asked to say whether they saw a solid object coming out from the region inside the inducers or just flat surfaces. Psychometric functions for each participant were fitted and plotted. Great variability in thresholds was found (threshold range: 6°-14°). The group threshold indicated that the pyramid was perceived with a probability of .5 with rotations of approximately 8°. The probability that the pyramid would be perceived dropped to a value less than .1 when the angle of rotation was 14°, which corresponded to the stimulus in which the real luminance edges are aligned to the cusps of the “mouth” of pacmen inducers. With further rotation angles, real luminance edges within the background crossed the illusory contours, thus preventing illusory contour formation, and the illusory pyramid was hardly perceived. This result suggested that the three-dimensional pyramid percept is strictly related to the formation of illusory contours.

The tolerance to misalignment between real luminance edges in the background and the pyramid perception lead us to produce a new version of the visual illusion. Instead of modifying the angle in the centre of the background to produce a tilting effect, we shifted the background left and right continuously. The amount of shift was suggested from experiment 2. The resulting percept is that of a pyramid rotating left and right on its vertical axis: the “Illusory Contoured Rotating Pyramid”.

Taken together, these results showed that the appearance of a solid pyramid is strictly related to the existence of illusory contours. The three defining aspects of illusory contour surfaces (illusory contour formation, brightness enhancement and depth stratification) were found in the illusory pyramid, thus extending them to illusory solid objects.

4. Investigations on Visual Masked Priming in Novel Contexts

4.1 Introduction

Priming refers to a change in speed and accuracy of the processing of a stimulus, following prior experience with the same, or a related, stimulus. This effect is usually measured indirectly, employing tasks that comprise the presentation of two consequent stimuli: a briefly displayed prime is followed by a target stimulus. Participants have to give their response regarding one aspect of the target. The prime can be related to the target (congruent trials) or not (incongruent trials). By measuring and comparing mean reaction times (mRTs) and error rates (ER) relative to congruent and incongruent trials, it is possible to demonstrate that participants are faster and more accurate in the first case compared to the latter.

A great amount of research stems from the seminal work of Meyer, Schvaneveldt, & Ruddy (1975) and Meyer & Schvaneveldt (1971) on associative priming, which reported faster responses to a word when it followed a semantically related word in comparison to a unrelated word (for a review, see Neely, 1991). Priming has been researched since then using different stimuli (words, numbers, geometrical shapes) and different tasks (lexical decisions, word-stem completion, number judgements, stimuli classification).

In the paradigm called *masked* priming, a third stimulus called mask is presented before and / or after the prime and before the target (e.g., Carr & Dagenback, 1990; Marcel, 1983). The role of the mask was initially thought to simply prevent participants from seeing the prime (in combination with brief prime presentation time and brief prime-target stimulus onset asynchronies - SOAs), thus blocking a strategic use of prime stimuli and preventing the formation of an episodic memory trace (Forster & Davis, 1984). These two aspects were considered as confounding factors in the study of priming. In fact, in the classical account for priming, it is assumed that the prime automatically creates some form of temporary change in the cognitive system (e.g., through spreading activation) that provides an advantage in the processing of the target, relative to the case in which the prime consists of an unrelated or neutral stimulus. For example, in a classic masked priming study, Forsters & Davis (ibid.) presented a mask (e.g., #####) for 500 msec, followed by a prime (e.g., straw vs. money) for 60 msec, followed by a target (e.g., straw); participants made accurate word / nonword lexical

decisions to the target more quickly when the prime was a repetition of the target. The facilitation of congruent over incongruent trials was explained with an automatic activation of entries in the mental lexicon. Spreading activation mechanisms were proposed to explain a similar facilitation between conceptually related prime-target pairs (e.g., doctor-nurse) (Logan, 1992; Posner & Snyder, 1975).

However, several recent studies have begun to seriously question this classic view.

Evidence against the explanation based on spreading activation was reported by finding masked repetition priming effects for nonwords in a lexical decision task (Bodner & Masson, 1997) and in a word-naming task (Bodner & Masson, 2004; Masson & Isaak, 1999), although nonwords do not have lexical entries indeed.

Moreover, it was found that the amount of priming depends on the proportion of valid (or congruent) trials within the experimental sequence: an effect named “prime validity effect”. When the proportion of valid trials is higher than invalid trials (e.g., valid to invalid, 3:1 vs 1:3), an increase in priming is obtained. Automatic spreading activation should act to the same extent and be unaffected by this list manipulation (Bodner & Masson, 2003).

A form of prime validity effect was found in semantic priming, and termed relatedness-proportion effect. As a possible explanation, Neely (Neely, 1991; Neely, Keefe, & Ross, 1989) postulated the existence of two distinct processes: an expectancy process and a semantic matching strategy. In short, participants generate a potential target after prime presentation, and they notice semantic relationships between prime and target and use them to influence lexical decisions. According to this hypothesis, when the proportion of valid trials is high, subjects consciously use the information provided by the prime to try to predict the identity of the upcoming target. This assumption was also supported by the fact that relatedness proportion effects were found to be typically absent when the SOA was less than 240 msec (Hutchison, 2007; Hutchison, Neely, & Johnson, 2001; Stolz & Neely, 1995): in this case, there is no time to strategically use prime information.

However, Bodner & Masson (2001) found larger masked repetition priming effects when the proportion between repetition and unrelated prime was .8 as opposed to .2 with SOAs as low as 45 msec. Prime-proportion effects were also found in a naming task (Bodner & Masson, 2004), showing that the effect is not restricted to binary judgements. Semantic priming is also affected by the relatedness proportion (Bodner & Masson, 2003). Other stimuli than words followed the same pattern of results: parity (e.g., odd / even) and magnitude (e.g., less / more than 5) judgements were affected by masked priming to a greater

extent when proportion of congruent trials was .8 rather than .2 (Bodner & Dypvik, 2005). Jaskowski, Skalska, & Verleger (2003) presented pairs of squares to subjects and asked them to indicate which of the two (e.g., on the left / right) had missing sectors on their vertical sides. When the proportion of side-congruent trials was .8 rather than .2, the priming effect was more pronounced. Nevertheless, in some form of priming, proportion effects have not been consistently found (Pecher, Zeelenberg, & Raaijmakers, 2002; Perea & Rosa, 2002).

These results suggested that masking does not prevent a context-specific use of the prime: participants can effectively modulate its influence in an adaptive manner, relying on the usefulness of the information supplied. Valid primes in congruent trials contain information that is helpful for responding to the target; invalid primes in incongruent trials contain irrelevant or interfering information. If valid information is presented in a larger proportion than invalid information, subjects adapt their reliance on primes.

In order to explain prime proportion effects, a memory recruitment account of priming has been proposed (Bodner, Masson, & Richard, 2006; Bodner & Dypvik, 2005; Bodner & Masson, 1997, 2001, 2003, 2004; Masson & Bodner, 2003; Whittlesea & Jacoby, 1990). The basic assumption is that processing operations applied to the prime create a new memory resource that can be retroactively recruited to assist subsequent target processing, whereas in the classical account a proactive change is produced by the prime, which enables a more efficient encoding of the target. Processing operations include every operation the cognitive system performs upon the prime with the aim of identifying and interpreting it (e.g., perceptual, orthographic, phonological, semantic) (Bodner & Dypvik, 2005). Compatibility of these operations with the one needed to respond to the target guides an eventual learning transfer. Whittlesea & Jacoby (1990) provided first evidence on a retroactive account of priming. An interpolated word was introduced between identical prime and target pairs: priming of naming responses of targets was greater when the interpolated word was degraded via case alternation in comparison to the non-degraded condition (e.g., pLaNt vs PLANT). The authors proposed that the cognitive system was more likely to rely on the prime when the processing was made more difficult through degradation. This situation is clearly incompatible with a spreading activation mechanism, because the spread of activation cannot be dependent on whether the subsequent interpolated word is degraded or not.

In this study, we asked ourselves whether the prime validity effect is modulated exclusively by the difference in the proportion of congruent and incongruent trials within the experimental sequence, or the serial presentation order could also play a role.

In priming experiments, as in many others, stimuli are presented using a standard randomization procedure. In this condition, more overall-frequent stimuli are also more likely to occur on the initial trials of a series, such that the serial presentation order co-varies with stimulus frequency. Is it possible to disentangle the effects of frequency (prime validity) from presentation order (primacy effect)?

Sokolov and colleagues (Sokolov, Pavlova, & Ehrenstein, 2000; Sokolov, Reissner, & Pavlova, 2004; Sokolov & Ehrenstein, 1996) presented clear psychophysical evidence that the serial presentation order, along with stimulus frequency, can profoundly alter human performance in perception and judgement tasks. In particular, they investigated the frequency effect in absolute judgement tasks: identical stimuli receive higher ratings when presented in a series with a greater proportion of small stimuli than when presented in a series with more frequent large stimuli (e.g., Marks, 1968; Parducci, 1956). To test whether this pattern of results is imputable only to a frequency effect, Sokolov et al. introduced a new ingenious context manipulation: by employing a biased randomization, conditions in which overall-rare stimuli occurred more frequently at the series' outset have been built and compared with conventional standard randomized stimuli sequences. In this way, it was possible to independently manipulate relative stimulus frequency of a) the first part of the sequence, and b) the whole sequence.

In absolute judgement tasks of visual velocity, different groups of participants were assigned to conditions with the same stimulus frequency (e.g., considering 5 different velocities: 10 – 10 – 10 – 10 – 10), or different (e.g., 20 – 14 – 8 – 4 – 4, and conversely, 4 – 4 – 8 – 14 – 20), and with standard randomization (e.g., 2 stimuli for each velocity are presented within the first 10 positions) or biased randomization (e.g., in the first 10 positions, the distribution of velocities mirrors the distribution relative to different-frequent stimuli conditions). The conventional frequency effect was reported. More interestingly, the authors reported a frequency-like primacy effect with overall equal-frequent velocities: identical velocities were rated faster when mainly slow rather than fast ones occurred on initial trials. In a third experiment, frequency and primacy effects were contrasted: in sequences with overall-frequent slow velocities, mainly fast ones occurred in the first 10 positions, whereas in sequences with overall-frequent fast velocities, mainly slow velocities did. No differences were found between these two conditions, suggesting that the two effects cancelled each

other. Sokolov et al. concluded that the conventional frequency effect represents a combination of a “pure” frequency effect and a primacy effect.

By examining prime validity effects while also taking into account serial order (primacy) effects, we attempted to further investigate the mechanisms underlying masked priming, and specifically test the recently proposed memory recruitment account of priming.

In a series of experiments, participants pressed a key to indicate whether or not a target square had gaps in its outline (a procedure inspired by Jaskowski et al., 2003). In a trial, two other stimuli were presented prior to the target: either a congruent or incongruent prime (same/different square, respectively), and a mask (square with dotted outline). In between-subject designs, we varied the frequency of congruent and incongruent trials in the series (1:1, 1:3, and 3:1) and serial order of presentation (either congruent or incongruent trials were more, or equally, likely to occur at the series outset), for a total of seven different conditions (see table 4.1).

In Experiment 1, we controlled the presence of a reliable priming effect in our procedure, employing standard randomized equally frequent sequences of congruent and incongruent trials (condition 7).

In Experiment 2, only the serial presentation order was manipulated, so that in sequences with the same number of congruent and incongruent trials, mainly congruent (condition 1) or incongruent (condition 2) ones occurred more frequently at the beginning.

In Experiment 3, the overall frequency of trials was modified, thus obtaining more congruent (condition 5) or incongruent (condition 6) trials, presented with standard randomization. The relative frequency of each type of trial in the first part of the sequence (12 trials) corresponded to the overall frequency: we named these two *concordant* conditions.

In Experiment 4, we contrasted frequency and serial order effects, by adding two *discordant* conditions, in which overall-rare stimuli occurred more frequently at the beginning.

4.2 Experiment 1: Priming Experiment

The aim of Experiment 1 was to verify the presence of a reliable visual masked priming effect. Participants pressed a key to indicate whether or not a target square had gaps in its outline. In a trial, two other stimuli were presented prior to the target: either a congruent or incongruent prime (same/different square, respectively), and a mask (square with dotted outline).

4.2.1 Methods

Participants. A total of 8 volunteer participants (undergraduate psychology students; 6 females; mean age 22, range 17-30 years) took part in the experiment. All participants were naïve regarding the purpose of the experiment. All were right-handed and had normal or corrected-to-normal vision.

Stimuli and apparatus. We used three consecutive stimuli presented on a trial: a prime, a mask, and a target. Each one was represented as a bright-outline square of the same dimensions. Two different kinds of squares were used both as the prime and target stimuli. One square had an intact outline (80 pixels wide; a *closed* stimulus type), whereas the other was created by removing a part (35 pixels) of the outline in the middle of both vertical sides of the square (an *open* stimulus type). The mask stimulus was obtained by drawing an intact square with a dotted outline (5 pixels between each 5-pixel dot). Each square subtended 2.31 x 2.31 degrees of visual angle, from an observation distance of 70 cm. See figure 4.1 for trial description.

The stimuli were presented in black on white on a 17-inch. monitor with a refresh rate of 75 Hz driven by the Matlab Psychophysics Toolbox extensions for Microsoft Windows (Brainard, 1997; Pelli, 1997), running on a Pentium 4 personal computer. The duration of each screen frame was 13.3 msec.

Four different types of trials were built by using the *open* and *closed* square stimuli: two congruent trial types (when the prime and the target stimuli were the same: *open-open*, *closed-closed*) and two incongruent trial types (when the prime and the target stimuli were different: *open-closed*, *closed-open*). The relative number of distinct trials within each of the two types of trials was always equal (e.g., open-open/closed-closed, for congruent trials, 1:1)

and balanced throughout the experiments. A total of 200 trials of both types (100 congruent and 100 incongruent) were presented in standard computer assisted randomized order.

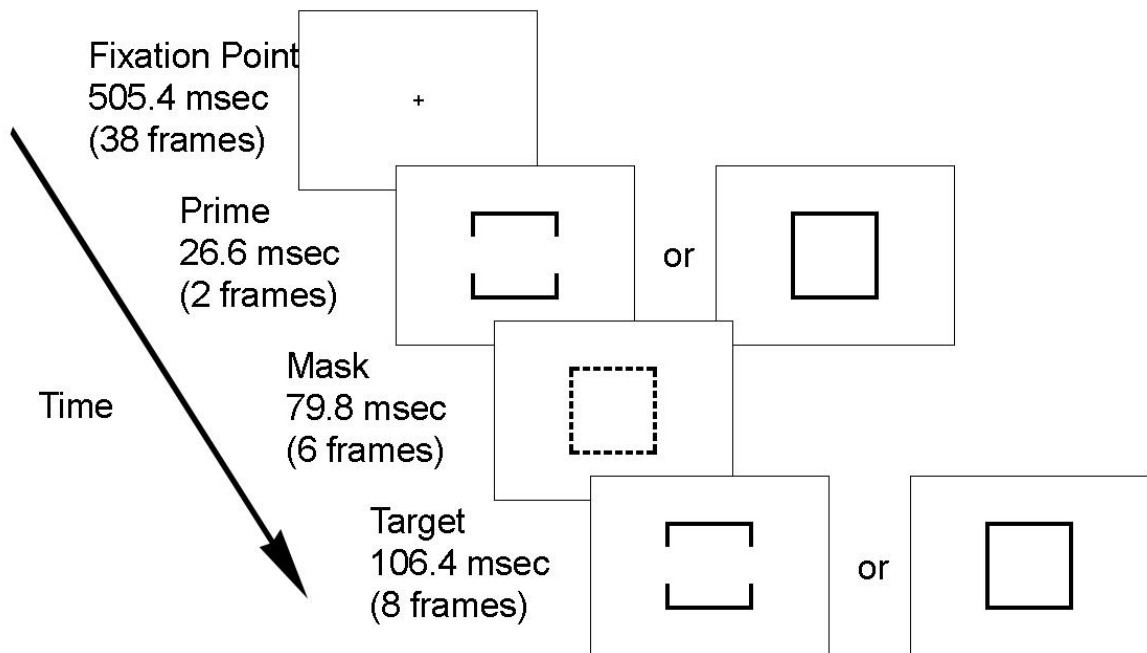


Fig. 4.1. Trial description. A fixation point was followed by a prime, a mask and a target. Two distinct kinds of squares were used both as the prime and target stimuli. One square had an intact outline (closed stimulus type), whereas the other was created by removing a part of the squares' vertical sides (an open stimulus type). Prime-target stimulus onset asynchrony (SOA) was 106.4 msec. Participants had to make rapid responses with their left or right hand depending on whether a square with open or closed sides was presented as a target.

Cond. No.	Cong. / Incong. Base Rate	Trial Randomization	Frequent Outset Trials
1	1 : 1 (100c : 100i)	biased	congruent
2	1 : 1 (100c : 100i)	biased	incongruent
3	3 : 1 (150c : 50i)	biased	incongruent
4	1 : 3 (50c : 150i)	biased	congruent
5	3 : 1 (150c : 50i)	standard	congruent
6	1 : 3 (50c : 150i)	standard	incongruent
7	1 : 1 (100c : 100i)	standard	none

Table 4.1. Description of the seven experimental conditions employed in the experiments. Condition 7 in Experiment 1; Conditions 1 and 2 in Experiment 2; Conditions 5 and 6 in Experiment 3; Conditions 3, 4, 5, 6 in Experiment 4.

Procedure. The experimental session started automatically after the participant entered information about gender and age and confirmed they understood the on-screen instructions.

Every trial started with a fixation aid: a cross in the middle of the screen was shown for approximately half a second (505 msec, 38 screen frames). After that, three stimuli were consecutively presented: the first stimulus (prime) was shown for two screen frames (26.6 msec), the second one (mask) for six frames (79.8 msec), the third one (target) for eight frames (106.4 msec). That is, the prime-target SOA was 106.4 msec with a mask presented in-between.

Participants had to make rapid responses with their left or right hand depending on whether a square with open or closed sides was presented as a target. The two *Control* keys on the PC keyboard were labelled as *open* or *closed* square. Label position was counterbalanced between participants. No information about stimulus probabilities or any familiarization trials were given to the participants prior to the experiment.

After a short break at the end of the session, participants had to complete a supplementary Priming Identification Procedure (see below) that served to assess the visibility of primes in the main experiment.

Participants viewed the stimuli with both eyes using a head-and-chinrest to ensure constant observation distance. The experiments were carried out in a dimly-lit room. No feedback was given regarding the participant's performance.

4.2.2 Results

A repeated measures analysis of variance was performed on the data relative to correct responses. Student's t-tests with Bonferroni correction were used for post hoc comparisons. Where appropriate, Greenhouse–Geisser adjustments to the degrees of freedom were performed. Results are represented in figure 4.2.

A significant difference between congruent and incongruent trials was found relative to mean reaction times ($F_{(1,7)} = 45.598, p = .0001$; mRTs congruent trials = 414 msec., mRTs incongruent trials = 453 msec.) and error rates ($F_{(1,7)} = 12.320, <p = .010$; ER congruent trials = 1.52 %, ER incongruent trials = 4.57 %). Participants were faster and more accurate when the target square was presented after an identical masked square. This result was in agreement with previous findings and allowed us to proceed with order and frequency manipulations using this procedure.

4.3 Experiment 2: Biasing the serial presentation order

Prime validity effects were usually obtained comparing sequences with more valid (congruent) or invalid (incongruent) trials. Here, we asked ourselves whether it is possible to obtain a similar result by manipulating stimuli presentation order only. Maintaining an equal proportion of the two types of trials within the experimental sequences, we applied a biased randomization making congruent or incongruent trials to appear more frequently in the first part of the sequence.

Results from Experiment 1 confirmed the presence of a priming effect using our procedure, thus allowing us to proceed with additional manipulations.

4.3.1 Methods

Participants. A total of 16 volunteer participants (undergraduate psychology students; 12 females; mean age 25, range 18-40 years) took part in the experiment. All participants were naïve regarding the purpose of the experiment. All were right-handed and had normal or corrected-to-normal vision.

Stimuli, apparatus and procedure. The experimental setup, stimuli, and procedure were identical to those in Experiments 1. The only difference from Experiment 1 was that Experiment 2 relied on stimulus sets with a different presentation order: in one condition, congruent trials were more frequent at the beginning of the sequence; in the other, incongruent trials were more frequent at the beginning. In the following paragraph we describe the generation of experimental sequences.

Generation of experimental sequences. Two types of experimental sequences (series) with equal-frequent congruent and incongruent stimuli but different serial presentation orders were generated, in which either congruent or incongruent trials dominated the series' outset. The biased experimental series was created using a modified version of the algorithm originally proposed in Sokolov et al. (2000) and reported below.

(1) Take 48 trials with a ratio between congruent and incongruent trials of 1:1 (i.e., 24 congruent and 24 incongruent). (2) Generate a source set by multiplying one of the two types of trials by a factor of nine (e.g., $24 \times 9 = 219$ congruent and 24 incongruent). (3) Randomize the 243 trials ($219 + 24$) in a standard computer-based way. (4) Take twelve initial occurrences of the trial type that was multiplied by nine at step 2 (here, congruent trials) counting from the beginning of the randomized source sequence. Count the occurrences of the other trial type (here, incongruent trials) found between them, k . (5) Complete the presentation series up to a total of 200 trials with the lacking occurrences of both stimuli. In our example, for a series of 200 trials with a ratio of 1:1 (congruent/incongruent), we need 88 additional ($100 - 12$) congruent trials and $100 - k$ incongruent trials. Finally, randomize these ($88 + 100 - k$) trials in a standard, computer-assisted way to get a homogeneous (non-biased) concluding part of the presentation series, and attach it to the initial biased portion of the series after the twelfth congruent trial. Thus, the resulting biased series comprised 100 congruent and 100 incongruent trials, although mainly congruent trials were presented at the beginning of the series. The same algorithm was applied to generate a biased series with mainly incongruent trials presented at the series' outset. Two additional series (one with mainly congruent trials, and the other with mainly incongruent trials presented at the series outset) were also produced in order to control for any series effects.

4.3.2 Results

A mixed repeated measures analysis of variance was performed on the dataset relative to correct responses. Student's t-tests with Bonferroni correction were used for post hoc comparisons. Where appropriate, Greenhouse–Geisser adjustments to the degrees of freedom were performed.

A significant main effect of type of trial was found both on mean reaction times ($F_{(1,14)} = 18.651, p = .001$; mRTs congruent trials = 404 msec., mRTs incongruent trials = 445 msec.) and error rates ($F_{(1,14)} = 8.319, p = .012$; ER congruent trials = 2.15 %, ER incongruent trials = 6.05 %).

A significant main effect of order factor was found on mRTs ($F_{(1,14)} = 7.680, p = .015$; mRTs with congruent trials more frequent at the beginning = 387 msec.; mRTs with incongruent trials more frequent at the beginning = 462 msec.). Results are reported in figure 4.2.

The first result confirmed the existence of a priming effect, when comparing congruent and incongruent trials both on participants' speed and accuracy. The second result

showed uniformly reduced mean reaction times when congruent trials rather than incongruent are more frequent at the beginning of the experimental sequence, even if the overall frequency of congruent and incongruent trials is the same. The lack of a significant interaction between Type of Trial and Order factors suggested that the amount of priming in the two conditions is not statistically different. The serial order affected global identification of the target, rather than enhancing priming.

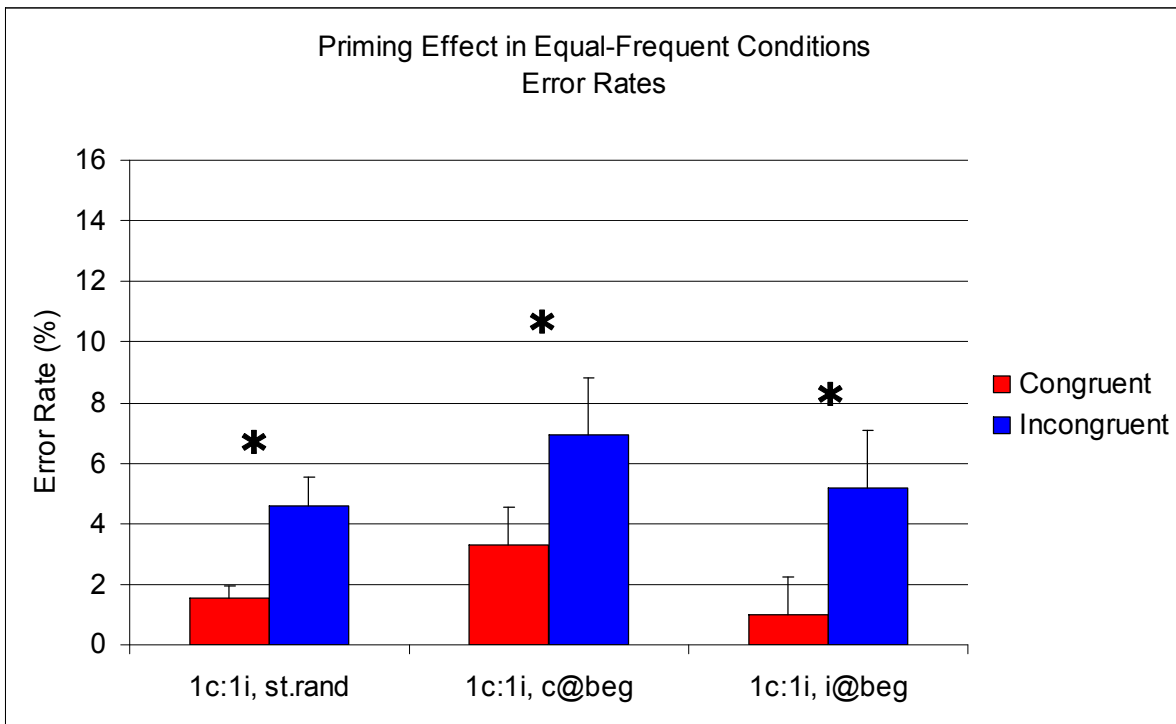
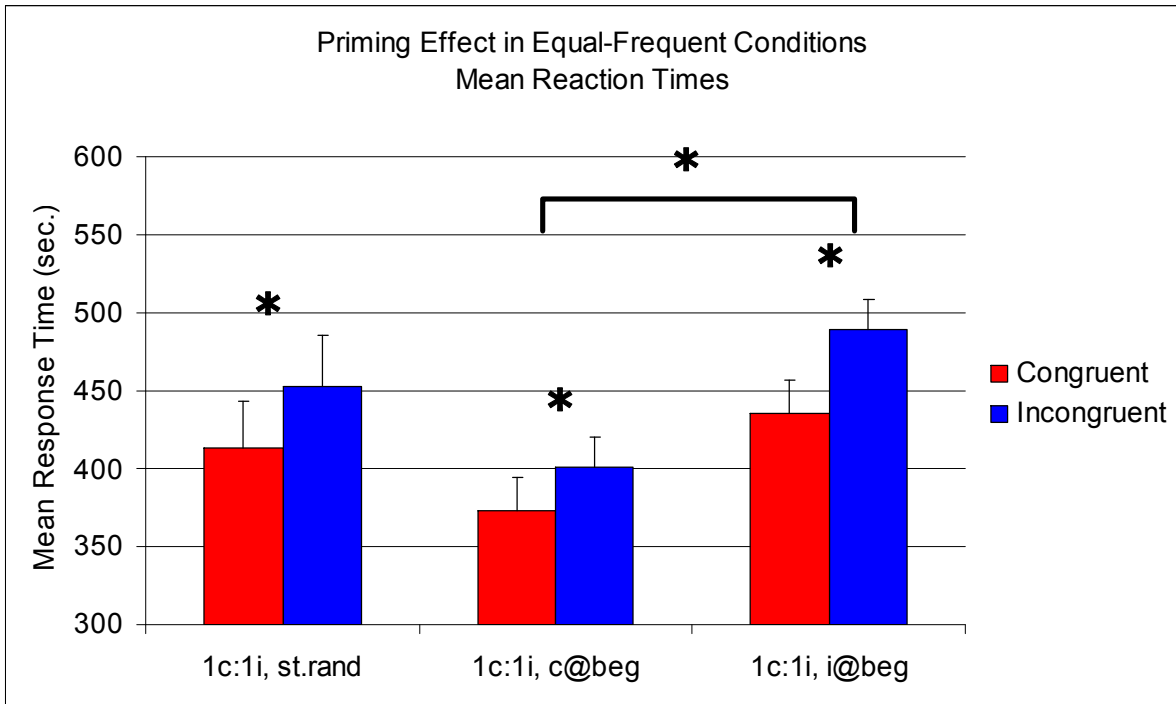


Fig. 4.2. Results of Experiments 1 and 2. Mean Reaction times (top) and error rates (above) relative to the conditions with equal-frequent congruent and incongruent trials. A reliable priming effect was found for the condition with unbiased presentation order (left) and for the conditions with more congruent (centre) and incongruent (right) trials at the series' outset. The main effect on mean reaction times by presentation order did not affect the amount of priming, but general identification: when congruent trials rather than incongruent were presented more frequently at the beginning, reaction times were uniformly reduced. Error bars represent standard error.

4.4 Experiment 3: Conventional Frequency effect

The aim of this experiment is to determine whether the prime validity effect in visual masked priming can be replicated using our procedure. Two conditions with more congruent or incongruent trials (ratios between congruent and incongruent trials: 1c:3i and conversely, 1c:3i) and standard randomization were compared.

4.4.1 Methods

Participants. A total of 16 volunteer participants (undergraduate psychology students; 13 females; mean age 27, range 20-37 years), different from those who participated in Experiments 1 and 2, took part in the experiment. All participants were naïve regarding the purpose of the experiment. All were right-handed and had normal or corrected-to-normal vision.

Stimuli, apparatus, and procedure. The experimental setup, stimuli, and procedure were identical to those in Experiments 1 and 2. The only difference was that now we used stimulus sets with different proportion of congruent and incongruent trials. However, in contrast to Experiment 2, we did not introduce any bias when randomizing the sets.

Generation of experimental sequences. Two types of experimental sequences (series) were generated, in which frequent trials occur mainly on the initial part of the series. The frequency of occurrence ratio between congruent and incongruent trials was either 1:3 or 3:1 yielding a total of 200 trials composed by 50 congruent and 150 incongruent trials or vice versa. Standard computer-based randomization was used to generate the two sequences.

4.4.2 Results

A mixed repeated measures analysis of variance was performed on the dataset relative to correct responses. Student's t-tests with Bonferroni correction were used for post hoc

comparisons. Where appropriate, Greenhouse–Geisser adjustments to the degrees of freedom were performed. Results are plotted in figure 4.3.

A significant main effect of type of trial was found both on mean reaction times ($F_{(1,14)} = 31.160$, $p = .0001$; mRTs congruent trials = 365 msec., mRTs incongruent trials = 400 msec.) and error rates ($F_{(1,14)} = 13.951$, $p = .002$; ER congruent trials = 2.80 %, ER incongruent trials = 8.37 %).

Significant interaction between type of trial and frequency factors was found both on mRTs ($F_{(1,14)} = 17.251$, $p = .001$) and on ER ($F_{(1,14)} = 9.745$, $p = .008$). Post hoc comparison with Student's t-test with Bonferroni correction showed a significant difference between mRTs for congruent and incongruent trials only when congruent trials were more frequent ($t = -5.416$, $d.f = 7$, $p < .001$; mRTs: congruent = 369 msec., incongruent = 431 msec.). The same difference for ER was near significance ($t = -3.795$, $d.f = 7$, $p = .007$; ER: congruent = 2.02 %, incongruent = 12.24 %).

The first result confirmed again the existence of a priming effect, when comparing congruent and incongruent trials both on participants' speed and accuracy.

The second result showed a striking interaction between the type of trial and frequency: when congruent trials are more frequent (here, both overall and at the beginning of the sequence), a priming effect on mRTs and ER is present. However, when incongruent trials are more frequent, priming is completely abolished. The frequency effect indeed affects the amount of priming (while, as seen in experiment 2, serial order affected global identification of the target).

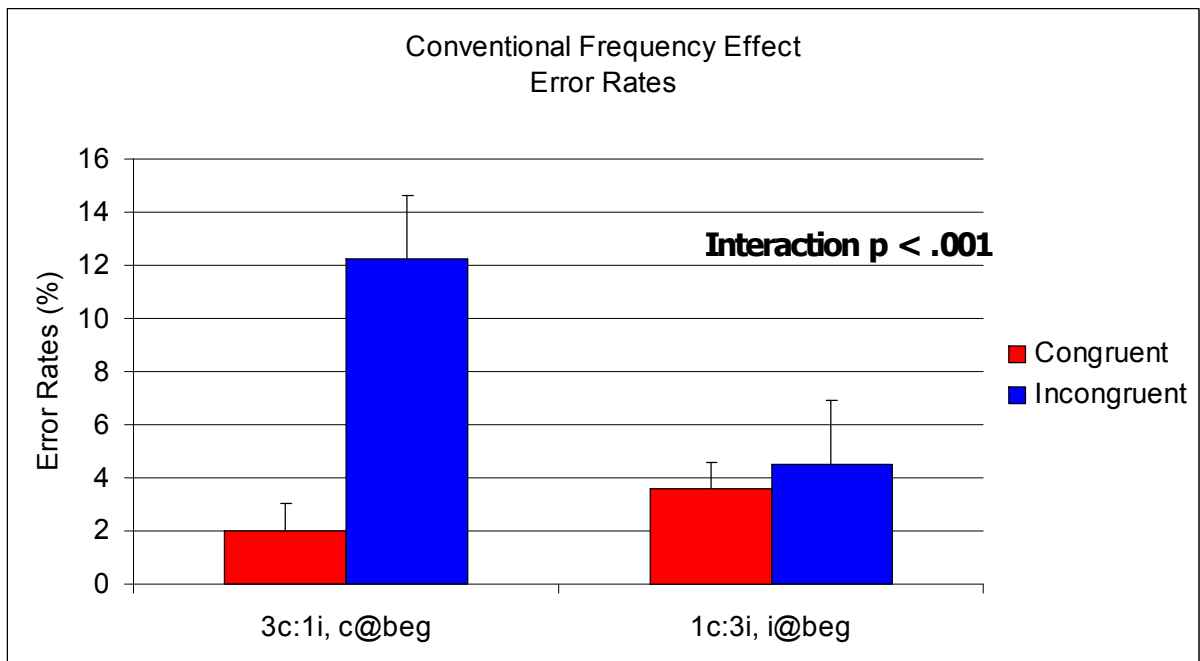
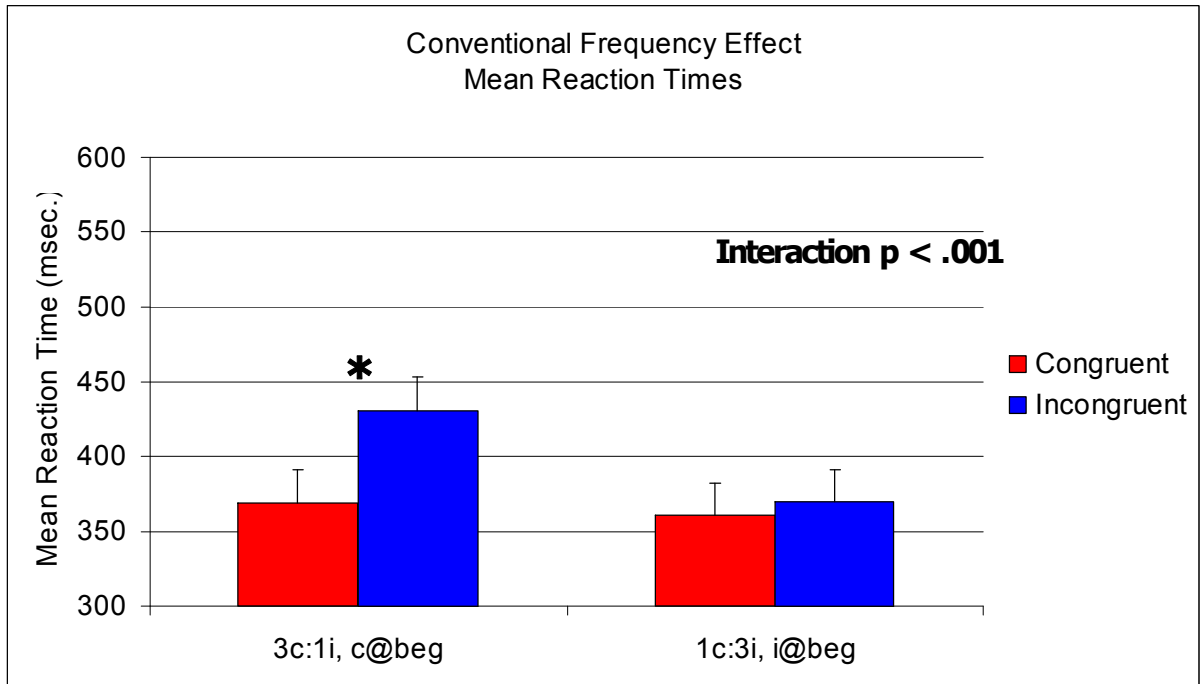


Fig. 4.3. Results from Experiment 3. Priming on mean reaction times and error rates in conditions with differently frequent congruent or incongruent trials and standard randomization. In both cases, significant interactions indicated the complete abolition of priming when incongruent trials are more frequent. Error bars represent standard error.

4.5 Experiment 4: Combining the Primacy and Frequency Effects

In this last series of comparisons, we investigated the combination of primacy and frequency effects. In a 2 (Type of Trial: congruent / incongruent) x 2 (Frequency: more congruent trials / more incongruent trials) x 2 (Order: at the beginning of the sequence, more congruent / incongruent trials) factorial design, we examined the primacy effect in sequences with unequal proportions of congruent and incongruent trials and frequency effects in sequences where congruent or incongruent trials were more frequent at the beginning.

4.5.1 Methods

Participants. A total of 32 volunteer participants (undergraduate psychology students; 27 females; mean age 27, range 19-47 years), different from those who participated in Experiment 1 and 2, took part in the experiment. The two conditions corresponding to the conventional frequency effect were taken from experiment 3. All participants were naïve regarding the purpose of the experiment. All were right-handed and had normal or corrected-to-normal vision.

Stimuli, apparatus, and procedure. The experimental setup, stimuli, and procedure were identical to those described in Experiment 1. The two concordant conditions were already examined in experiment 3. Two discordant conditions were built and employed, so that rare stimuli had a greater probability to occur during the initial trials of a run. A description of the algorithm used to build the sequences follows.

Generation of experimental sequences. Two types of discordant experimental sequences (series) were generated, in which overall infrequent trials occurred mainly in the initial portion of the series. In distinct discordant series, the frequency of occurrence for congruent and incongruent trials was either 1:3 or 3:1, yielding a total of 200 trials per series comprised of 50 congruent and 150 incongruent trials or vice versa, respectively.

We employed the following algorithm (a modified version of the originally proposed in Sokolov et al., 2000) to build the two discordant sequences. (1) Take 48 trials with a ratio between congruent and incongruent trials of 1:3 (i.e., 12 congruent and 36 incongruent). (2) Generate a source set by multiplying the lower frequency by a factor of nine (e.g., $12 \times 9 =$

108 congruent and 36 incongruent). (3) Randomize the 144 trials (108 + 36) in a standard computer-assisted way. (4) Take twelve initial occurrences of the trials with a lower frequency at step 1 (here, congruent trials) counting from the beginning of the randomized source sequence. Count the occurrences of the trials with a higher frequency at step 1 (here, incongruent trials) between them, k . (5) Complete the presentation series up to 200 trials with the lacking occurrences of both stimuli. In our example, for a series of 200 trials with a ratio 1:3, we need 38 (= 50 - 12) congruent trials and 150- k incongruent trials. Finally, randomize these (38 + 150 - k) trials in a standard way to get a homogeneous (non-biased) concluding part of the presentation series, and attach it to the initial biased portion of the series after the twelfth congruent trial. Thus, the resulting biased series comprised 50 congruent and 150 incongruent trials, although mainly (on overall infrequent) congruent trials were presented at the beginning of the series. The same algorithm was applied to generate a biased series with mainly (on overall infrequent) incongruent trials presented at the series' outset. Two additional discordant series were also produced in order to control for any series effects.

4.5.2 Results

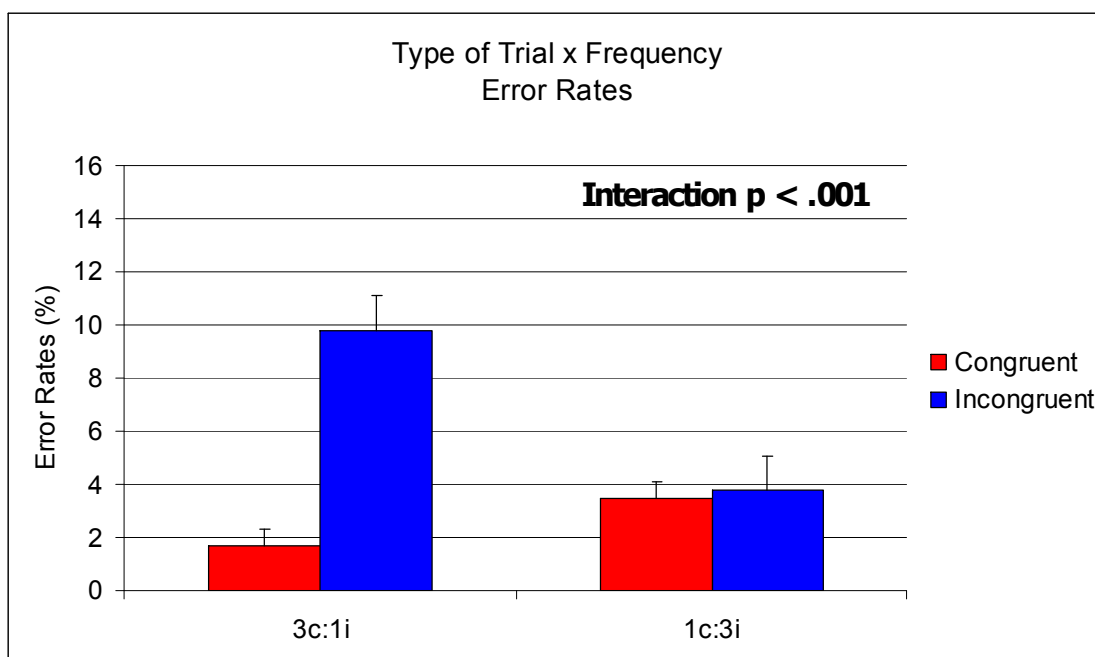
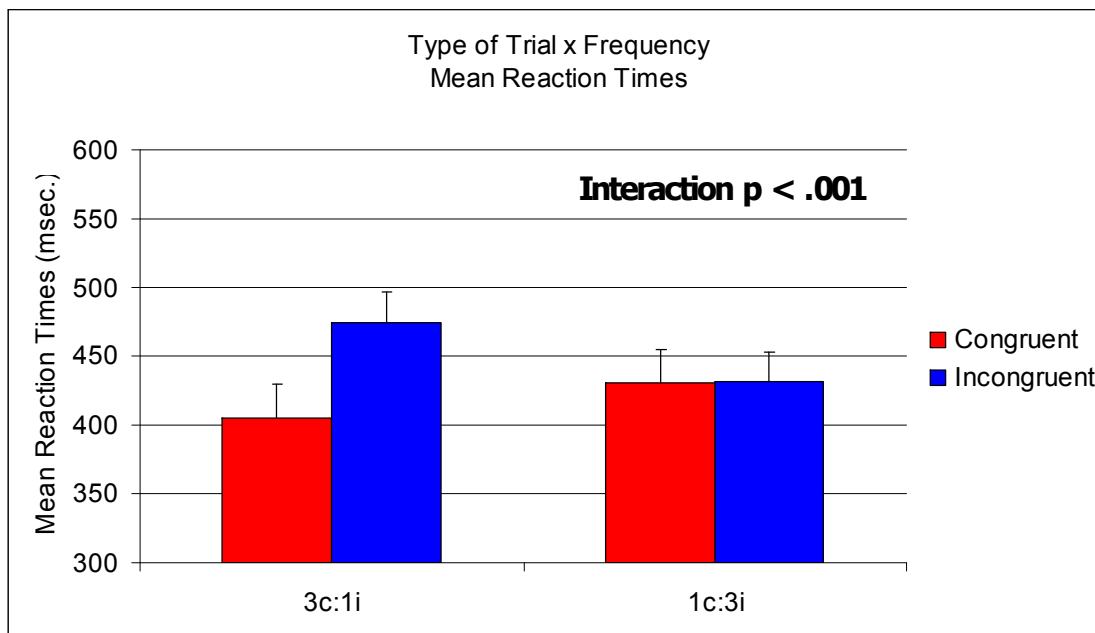
A mixed repeated measures analysis of variance was performed on the data relative to correct responses. Student's t-tests with Bonferroni correction were used for post hoc comparisons. Where appropriate, Greenhouse–Geisser adjustments to the degrees of freedom were performed. Significant results are plotted in figure 4.4.

A main effect of Type of Trial factor was found both on mean reaction times ($F_{(1,28)} = 38.836$, $p = .0001$; mRTs: congruent trials = 418 msec., incongruent trials = 453 msec.) and error rates ($F_{(1,28)} = 25.842$, $p = .0001$; ER: congruent trials = 2.558, incongruent trials = 6.787), confirming the existence of a reliable priming effect when considering all the four conditions.

A significant interaction between Type of Trial and Frequency factors was found both on mean reaction times ($F_{(1,28)} = 35.870$, $p = .0001$) and error rates ($F_{(1,28)} = 22.073$, $p = .0001$). Post hoc comparisons clearly showed that the priming effect on speed and accuracy is completely abolished when incongruent trials are more frequent in the whole sequence (mRTs more congruent trials: $t = -2.547$, $d.f. = 14$, $p < .025$; ER more congruent trials: $t = -5.371$, $d.f. = 15$, $p < .025$). A significant interaction between Order and Frequency factors was found in reaction times ($F_{(1,28)} = 11.292$, $p = .002$). Post hoc comparisons confirmed that mRTs in

concordant conditions were significantly lower in comparison to discordant conditions ($t = -3.432, d.f. = 30, p < .025$).

These results showed a uniform reduction of mean reaction times (both for congruent and incongruent trials) for concordant conditions in comparison to discordant conditions. When frequent trials within the sequence are also more frequent at the beginning, participants are faster in comparison to the case in which rare trials are more frequent in the beginning.



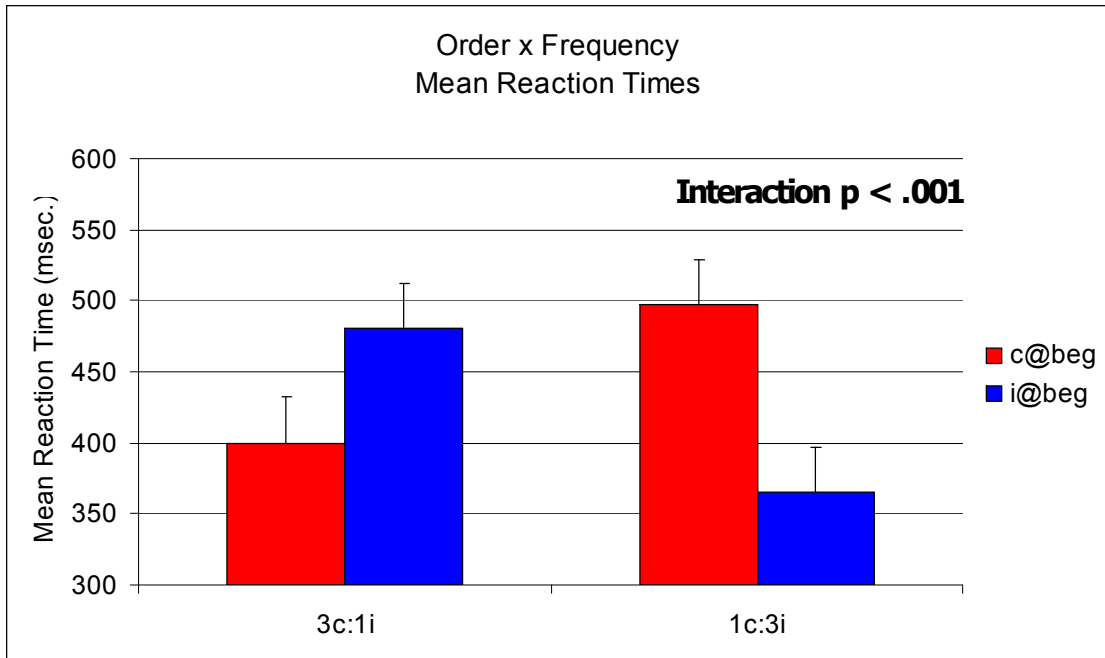


Fig. 4.4. Results from Experiment 4. Significant interaction on mean reaction times (top) and error rates (middle) indicated the absence of priming in conditions with more frequent incongruent trials, regardless of the presentation order. The significant interaction between order and frequency (above) showed a reduction of mRTs in congruent conditions in comparison to incongruent ones. Error bars represent standard error.

4.6 Prime Identification Procedure

After the main experimental session, each participant ($N = 56$) carried out a prime identification procedure session. Participants had to make rapid responses with their left or right hand depending on whether they thought a square with open or closed sides was presented as a prime. The two *Control* keys on the PC keyboard were labelled as *open* or *closed* square. Label position was counterbalanced between subjects. An equal number ($n=40$) of congruent and incongruent trials giving rise to a total of 80 trials, were randomized in a standard computer-assisted way and presented to the participants with the same procedure as that described in Experiment 1. We used an equal number of trials of each type (20 open-open and 20 closed-closed for congruent; 20 open-closed and 20 closed-open for incongruent trials). No feedback was given regarding the participant's performance. No information about stimulus probabilities or any familiarization trials were given to the participants prior to the experiment.

Participants recognized the prime with a mean value of 67.6 % (conversely, error rate corresponded to 32.4 %; range: 10.13 % – 55.70 %). Chi Square tests were employed to compare participants' performance on prime recognition: for 37 out of 56 participants, a significant difference between right and wrong answers was reported, indicating they were responding above chance level.

4.7 General Discussion

In a series of masked-priming experiments we examined how the frequency and serial order of congruent and incongruent trials affect masked priming of visual target identification. More specifically, we wanted to test whether prime validity effects were affected only by frequency, or presentation order could also play a role.

In Experiment 1, we employed standard randomization on a sequence of equally frequent congruent and incongruent trials. This conventional context showed a priming effect on speed and accuracy of participants when the prime and target were identical, thus allowing us to introduce order and frequency manipulations.

In Experiment 2, the presentation order of trials was modified, making congruent or incongruent trials to occur more frequently at the beginning of the sequence, while keeping their overall frequency identical. This was made possible by using biased randomization. The aim of this experiment was to test whether it was possible to obtain a prime validity-like effect by manipulating the first part of the sequence only. We found an effect on identification rather than on priming: when congruent trials were more frequent on earlier trials, reaction times relative to both congruent and incongruent trials were shorter. Thus, early experiences with frequent congruent trials promoted identification, independently of trial type. The priming effect, considered as the difference between mean reaction times of congruent and incongruent trials, was not altered by serial order.

In Experiment 3, the overall frequency of congruent and incongruent trials was manipulated. Standard randomization was employed to obtain sequences with overall-frequent trials to also occur more frequently at the beginning of the sequence. We called these concordant conditions, since the ratio between congruent and incongruent trials on the whole sequence and at its beginning is the same. This experiment had the aim to verify the existence of a prime validity effect. This was indeed the case: priming effects on speed and accuracy were found when congruent trials were more frequent. Interestingly, no priming at all was

found when incongruent trials were more frequent. Frequency manipulations did have an effect on the amount of priming, rather than an on target identification (as seen for presentation order).

In Experiment 4, both presentation order and frequency were manipulated to disentangle the co-variation between the two factors, usually present in the existing literature. The two concordant conditions of experiment 3 were compared with two discordant conditions, in which overall-rare trials occurred more frequently at the beginning of the sequence. We obtained these conditions by using a biased randomization procedure. Frequency of congruent and incongruent trials was found to modulate priming effect both on participants' speed and accuracy: when incongruent trials were more frequent in the sequence, the priming effect is abolished, regardless of the presentation order. This finding extended Experiment 3 results, considering concordant and discordant conditions together.

Presentation order was found to interact with frequency effect in the identification of the target: in concordant conditions, participants were faster in recognizing the target when compared to discordant conditions. In other words, when the ratio between congruent and incongruent was not modified between the first and second part of the sequence, mean reaction times both for congruent and incongruent trials are shorter.

Moreover, reaction times are uniformly reduced with frequent incongruent trials compared to frequent congruent trials when mainly incongruent trials occurred at the series' outset.

Taken together, these results show that, in addition to within-trial (trial type), between-trials contextual modifications also strongly modulate masked priming of visual identification. We demonstrated for the first time that contextual serial order and frequency effects are experimentally dissociable: the former affects identification independently of trial type, while the latter affects both identification and the amount of priming.

The existence of a prime validity effect with a SOA as short as 106 msec. was found, even when it was contrasted with serial order. This result is in agreement with and extended the retrospective episodic theory of masked priming proposed by Bodner & Masson (2003). As pointed out by Stolz, Besner, & Carr (2005) in a theoretical review, theirs is the only theory that is compatible with prime validity effects at such a short SOA.

The cognitive system has the ability to modulate the influence of masked primes in an adaptive manner: participants are more likely to rely on prime recruitment when such recruitment is advantageous for target processing. This happened when congruent trials were

more frequent in the sequence, either when congruent or incongruent trials occurred more frequently at the beginning of the sequences.

In incongruent trials, prime retrieval is not advantageous for target processing, since the target is different from the prime and calls for the opposite response. To have a similar effect in this context, participants should rely on the rule “the prime is different from the target” to get advantageous information in this type of trial. This is indeed not the case: when incongruent trials are more frequent, priming is completely abolished, regardless the frequency distribution in the initial part of the sequence.

With equally frequent congruent and incongruent trials, the prime validity effect was not obtained with presentation order manipulation only. We can argue that, according to Bodner & Masson’s hypothesis, a frequent valid prime occurrence in the first twelve positions of the sequence is not enough to become an advantage. Or, conversely, the lack of differences in frequency of congruent and incongruent trials in the second part of the sequence could have obscured the initial advantage. It could be that some form of confirmation of the “calibration” adopted in the first part is needed to produce the effect. The change in the proportion of congruent and incongruent trials after the first twelve trials may have contributed in this way.

This hypothesis seems in agreement with the interaction between trials’ presentation order and frequency on general target identification (not prime validity): we found a uniform reduction of reaction times for concordant conditions compared to discordant conditions. In other words, participants were faster when the congruent / incongruent ratio did not change between the first and second part of the sequence. The change in relative frequency of congruent and incongruent trials from the first (12 trials) to the second (188 trials) part of the sequence introduced some sort of perturbation that uniformly slowed reaction times.

4.8 Short-term Effects Analysis

To further investigate mechanisms underlying masked priming and prime validity effect, we examined how the amount of priming changes within the sequence of trials. The seven experimental sequences described above were segmented in four parts, each including fifty trials. Each segment included the same or a different proportion of congruent and incongruent trials, depending on the experimental condition (see fig. 4.5 for details).

For example, in equal-frequent congruent and incongruent trial conditions (1,2,7), the proportion between congruent and incongruent trials in each segment is approximately the

same, with differences mainly in the first segment (respectively, condition 1: more congruent; condition 2: more incongruent; condition 7: same proportion) and in the last segment (respectively, condition 1: more incongruent; condition 2: more congruent; condition 7: same proportion).

We asked ourselves whether, by analyzing time course of priming in these four segments, it is possible to shed some light on how frequency and presentation order manipulation affected mean reaction times, although a finer segmentation could have been employed.

Data on mean reaction times and error rates have been re-coded to fit this partition (see fig. 4.6 for details). We performed several comparison using (mixed) repeated measures analysis of variance and Student's t-test with Bonferroni correction in post hoc comparison. We reported in the following section relevant findings only.

4.8.1 Results

Significant interactions between Type of Trial and Sequence Sector were found on mean reaction times in the condition with equal occurrence of congruent and incongruent trials and standard randomization ($F_{(3,21)} = 4.460$, $p = .014$). Post hoc comparisons with Bonferroni corrected Student's t-tests showed that, the priming effect was established in the second quarter of the sequence ($t = -7.228$, $d.f. = 7$, $p = .0001$; mRTs: congruent = 408 msec., incongruent = 442 msec.), enhanced in the third quarter ($t = -4.210$, $d.f. = 7$, $p = .004$; mRTs: congruent = 396 msec., incongruent = 441 msec.), and maintained to the end ($t = -3.488$, $d.f. = 7$, $p = .010$; mRTs: congruent = 413 msec., incongruent = 460 msec.).

In this standard condition, the priming effect was established after 100 trials, approximately 50 congruent and 50 incongruent. The effect was enhanced after 50 further trials and remained stable until the end of the sequence (200 trials).

In the two conditions with equally frequent congruent and incongruent trials but with a biased presentation order (serial order effect), the amount of priming was unaffected by the segmentation, suggesting a uniform time course for the difference between congruent and incongruent mean reaction times.

In the two conventional frequency effect conditions (also named concordant conditions), significant interactions on mean reaction times were found between Type of Trial and Sequence Sector (condition 5, more congruent trials: $F_{(3,21)} = 3.629$, $p = .030$; condition 6,

more incongruent trials: ($F_{(3,21)} = 5.169, p = .008$)). Post hoc comparisons showed that in both conditions a priming effect was established in the second sector and abolished in the third, but whereas in the condition with more congruent trials priming was present again in the fourth sector, in the other it was not restored. Interestingly, in concordant conditions it seemed that reaction times relative to the most frequent type of trials were uniform throughout the sequence, while those relative to the rarest trials experienced some fluctuations. Nevertheless, when more incongruent trials were in sequence, priming was harder to maintain.

Concerning the two discordant conditions (overall-rarest trials occurring more frequently at the beginning of the sequence), a significant interaction on mRTs between Type of Trial and Sequence Sector was found when congruent trials were more frequent (and incongruent trials are more frequent at the beginning: condition 3) ($F_{(3,18)} = 3.948, p = .025$). Post hoc analysis showed that priming was established in the second quarter of the sequence ($t = -3.942, d.f. = 6, p = .008$; mRTs: congruent = 412 msec., incongruent = 490 msec.), abolished in the second and restored in the final part of the sequence ($t = -7.831, d.f. = 6, p = .0001$; mRTs: congruent = 405 msec., incongruent = 492 msec.).

Frequency Distributions of Congruent and Incongruent Trials

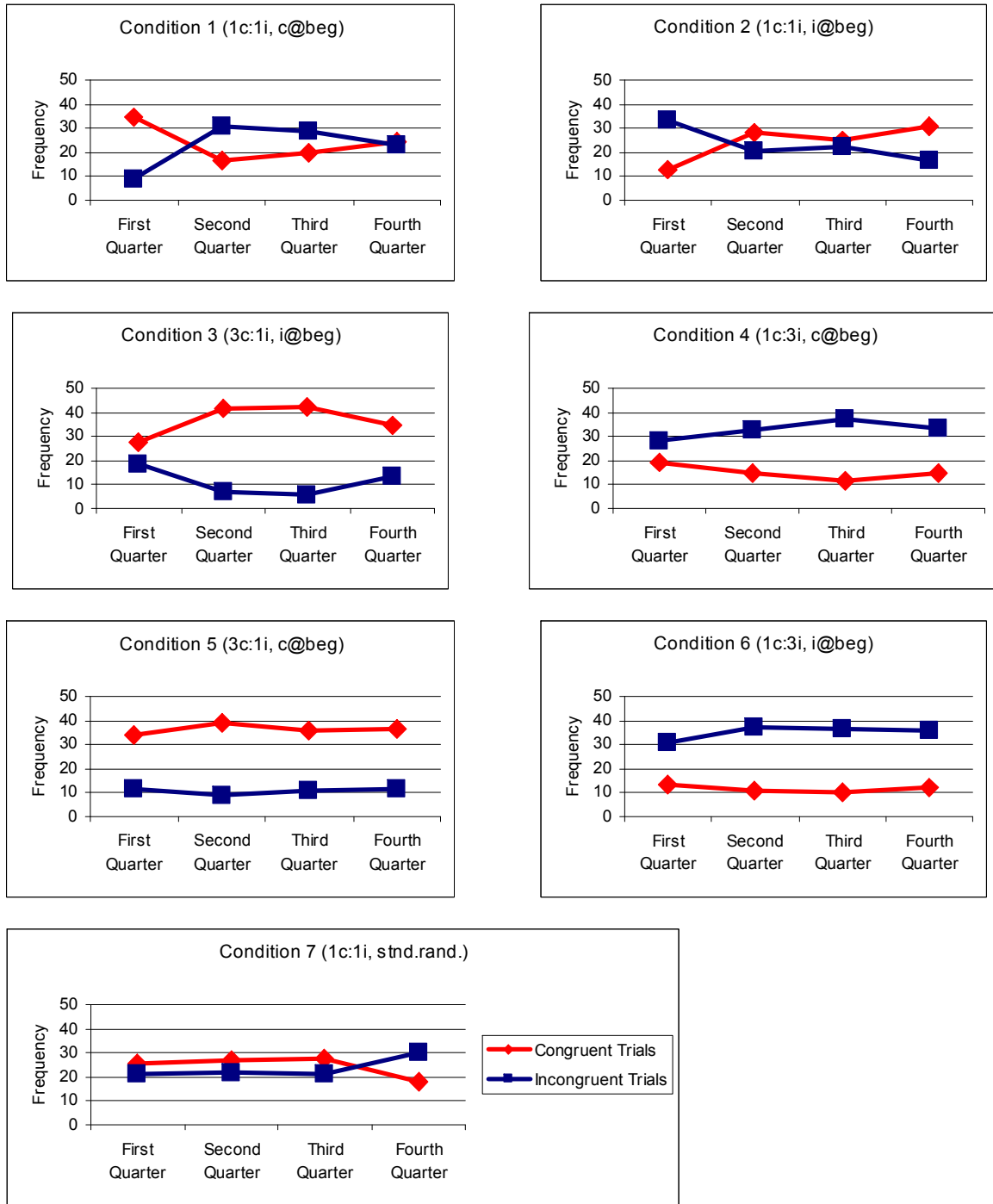


Fig. 4.5. Frequency of trials in each of the seven experimental conditions, after segmentation. Congruent trials (red) and incongruent trials (blue) within each sequence were segmented in four parts.

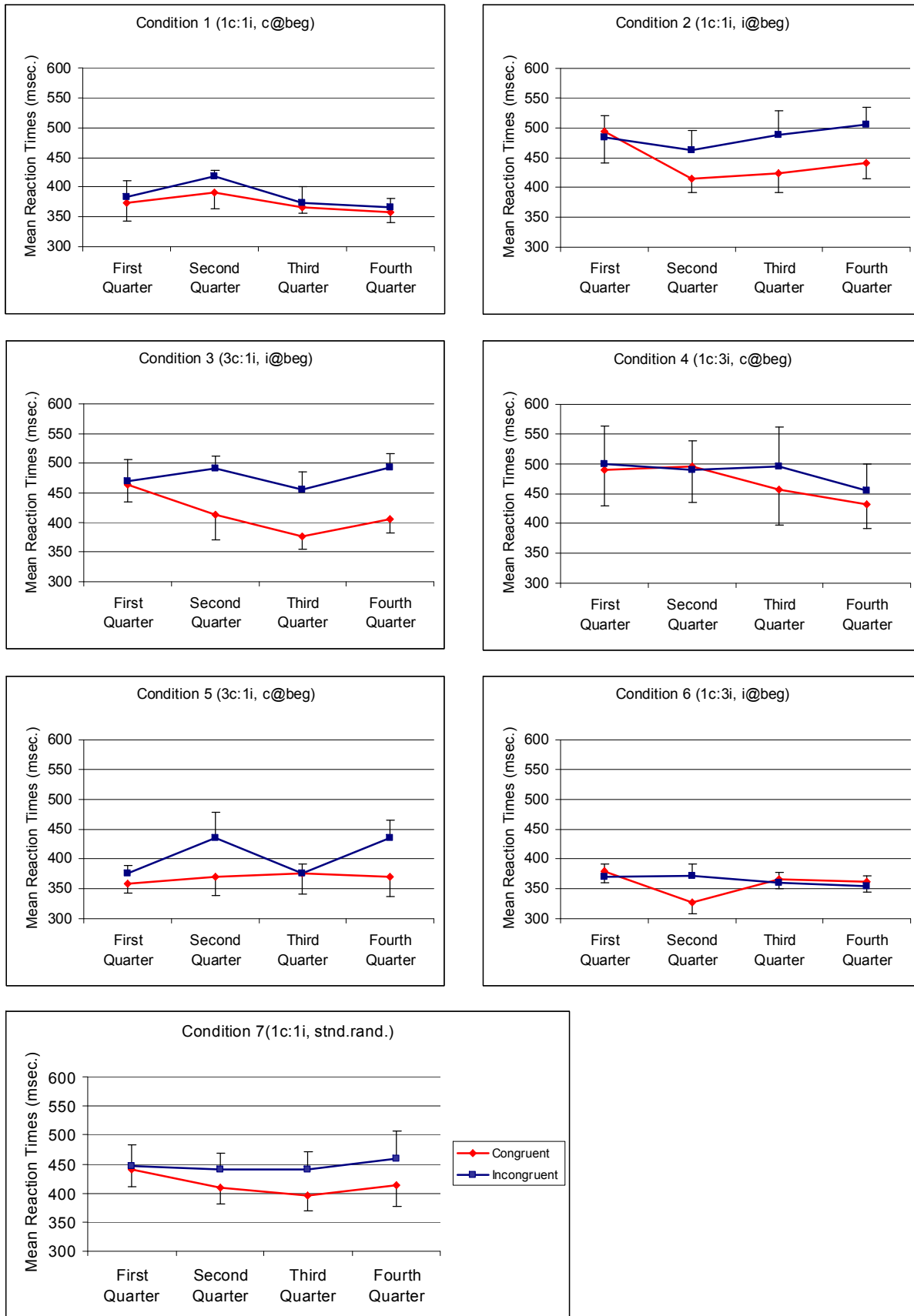


Fig. 4.6. Mean reaction times relative to each condition, after the segmentation in four sectors. Error bars represent standard error.

4.8.2 General Discussion on Short Term Effects

The aim of this experiment was to explore and describe the time course of priming effects. We segmented each experimental sequence of trials in four sectors, and compared mean reaction times relative to congruent and incongruent trials for each sector.

Our results showed that the priming effect on mean reaction times was sometimes subjected to statistically significant fluctuations: in general, priming was established in the second quarter of the sequence (i.e., between 50 and 100 trials: conditions 7, 5, 6, 3); subsequently, priming was maintained until the end when the proportion of congruent and incongruent trials was the same, and no biased randomization was introduced (condition 7). However, fluctuations were also present when congruent trials are more frequent (conditions 3, 5), regardless the presentation order, and followed a common pattern: priming was formed in the second sector, abolished in the third and re-established in the fourth sector (conditions 3, 5). When incongruent trials were more frequent (conditions 4, 6), the lack of priming prevented any modulation, although in the concordant condition (6), in the second sequence sector a priming effect was found.

An interesting observation came from the two concordant conditions (conditions 5 and 6): it seemed reasonable to claim that priming originated by the fluctuation of the less-frequent type of trial when its frequency of occurrence was not modified throughout the sequence. However, when this rarest trial occurred more frequently at the beginning, time course of priming was different: this reflected the interaction between frequency and presentation order factors, already discussed.

General Conclusions

In this thesis we examined how two widely researched phenomena were affected by new contexts, with the aim of bringing new findings towards their understanding. Illusory contour formation and visual masked priming are two intriguing aspects of, but not limited to, human perception. Although literally hundreds of studies were published on these subjects, their understanding is not complete.

The employment of heterogeneous backgrounds in illusory contour formation allowed us to bring new findings on depth stratification, a phenomenal percept that in the past has received lesser attention than the two others defining features of illusory contours, i.e., contour clarity and brightness enhancement. We found that depth stratification was enhanced in heterogeneous contexts, and that its perceptual course was independent of contour clarity and brightness enhancement. A result similar to the first one was reported by Spillmann and Redies (1981) using line-end inducers on a random-dot pattern. We have extended this observation to edge-type inducers. The second finding was suggested by Pinna et al. (2004), who however employed homogeneous backgrounds only: we extended it to heterogeneous backgrounds. We also documented the observation by Ramachandran et al. (1993), who reported that illusory contour clarity was enhanced with the support of real luminance edges within the background. Furthermore, we extended this claim through a range of texture coarseness values. These results were collected using a rating scale method: we employed the only method proposed in literature to measure depth stratification in illusory contours figures by Coren (1972) and Porac (1978). While in homogeneous contexts results were in agreement with previous findings, we found a sort of ceiling effect with the heterogeneous backgrounds. We postulated this was due to inherent positional cues within the texture we used. To draw any conclusion on the use of this indirect method, further investigations using different configurations will have to be carried out.

We also demonstrated that the employment of heterogeneous backgrounds with illusory contour configurations can give rise to particularly striking illusions. A new illusion, called the “Illusory Contoured Tilting Pyramid”, was described and tested with two psychophysical experiments. Their aim was to ascertain the causal role of illusory contours in this visual illusion. A new version of the illusion based on psychophysical data was built. This illusion obtained an excellent reception at the international contest “Best Visual Illusion of the Year Contest”, held in Sarasota in May 2007, where it was voted as the second best illusion of the year.

In the second part of this thesis, we reported a series of visual masked priming experiments with novel context manipulations. Previous research on priming has taken into account primarily the frequency of congruent and incongruent trials, e.g., the prime validity effect: when the proportion of congruent (valid) trials is higher than incongruent (invalid) trials, an increase in priming is obtained. Following the psychophysical findings on perception and judgement of Sokolov and colleagues (Sokolov, Pavlova, & Ehrenstein, 2000; Sokolov, Reissner, & Pavlova, 2004; Sokolov & Ehrenstein, 1996), we observed that when stimuli are presented with standard randomization, overall more-frequent stimuli also occurred more frequently during initial trials, such that the serial presentation order co-varies with stimulus frequency. We applied a *biased* randomization on experimental sequences using an algorithm proposed by Sokolov et al. (2000), and created a new context: conditions in which overall-rare stimuli occurred more frequently at the series' outset. In this way, it was possible to independently manipulate the stimulus relative frequency of a) the first part of the sequence, and b) the whole sequence. After finding a reliable priming effect on speed and accuracy of participants in a conventional context (Experiment 1), we tested whether presentation order alone could affect priming (Experiment 2). An effect on identification rather than on priming was found: early experiences with frequent congruent trials promoted identification, independently of trial type. Subsequently, we confirmed the existence of a prime validity effect (Experiment 3). Finally, we contrasted frequency (prime validity) and order (primacy) effects, to disentangle the co-variation between the two factors, usually present in the existing literature.

In an additional series of analyses, we examined the time course of priming on mean reaction times throughout the experimental sequences, showing that order and frequency manipulation affected priming diversely.

These results showed that, in addition to within-trial (trial type), between-trials contextual modifications also strongly modulate masked priming of visual identification. We demonstrated for the first time that contextual serial order and frequency effects are experimentally dissociable: the former affects identification independently of trial type, while the latter affects both identification and the amount of priming. The finding of a prime validity effect at such short SOA brought further evidence for the recently proposed theory of retrospective episodic theory of masked priming (Bodner & Masson, 2003).

To summarize: in this work, we extended previous knowledge on illusory contour formation and visual masked priming by introducing new contexts: heterogeneous backgrounds and a biased presentation order. In the first field of research, our results suggested the existence of a capture effect by illusory contour figures at the monocular level. In the second field, our results indicated that primacy (serial-order) and frequency effects on priming are dissociable and affect priming diversely (Sokolov, Guardini, & Pavlova, 2006, 2007).

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