SENSITIVITY TO TEXTURAL STATISTICS AFFECTS THE PERCEIVED SIZE OF A VISUAL OBJECT

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Abstract

Human vision exhibits peculiar sensitivity to specific global properties of visual stimuli. Visual objects are characterised by statistical textural properties, resulting in their "surface appearance". Texture grain provides information on the material composition of a visual object and can affect its perceived size. According to the Oppel-Kundt illusion, an area articulated in subparts appears larger than an empty one. Adopting a quantitative approach, we tested the perceived extension of square textures when basic textural properties like microelements' numerosity, spatial frequency and articulation of subparts (checkboards vs. random order) systematically varied. An illusory increment of area extension was generally found with textured stimuli. The perceptual enlargement increased with spatial frequency and decreased with microelements' number, indicating an independent analysis of the two basic properties. An ordered arrangement of subparts (as in checkboards) provided a larger effect than a random articulation. Those results demonstrate the relevance of processing textural statistics on perceiving the size of visual objects.

Several findings have demonstrated that the visual system is sensitive to specific statistical properties of visual stimuli (Ariely, 2001; Atchley & Andersen, 1995; Caelli & Julesz, 1979; Dakin & Watt, 1997; Giora & Casco, 2007; Haberman & Whitney, 2009; Julesz, 1965; Julesz, 1981; Kingdom, Hayes, & Field, 2001; Morgan, Chubb, & Solomon, 2008; Watamaniuk & Duchon, 1992). Seminal investigations on the visual sensitivity to the overall characteristics of a visual pattern, as spatial frequency (Campbell & Robson, 1968), supported the representation of the visual system as an "analyzer" that processes the stimulus by means of selective channels (Maffei & Fiorentini, 1973; Maffei & Fiorentini, 1977). Contrarily to the idea that visual analysis implies a hierarchical organisation of modules with increasing complexity (Marr, 1982; Neisser, 1967), global properties of visual stimuli can be processed earlier than singular features (Marchant & de Fockert, 2009; Navon, 1977; Parkes, Lund, Angelucci, Solomon, & Morgan, 2001).

Visual objects are characterised by a given *texture* (Karu, Jain, & Bolle, 1996), resulting in their *surface appearance*. Textural characteristics can be thought in terms of statistical properties of an image (Haralick, 1979; Zhang & Tan, 2002). Texture *grain* provides information on the material composition of a visual object (Adelson & Bergen, 1991) and can affect its perceived size (Gibson, 1950).

In the present research we discuss how processing peculiar statistical properties critically affect the perceived size of textured visual objects (Giora & Gori, in press). Phenomenological observations have pointed out that the subparts' articulation of a space affects its perceived size: a phenomenon commonly referred to as "Oppel-Kundt" illusion (Vicario, 2008). Verrillo & Graeff (1970) and Bazzeo & Zanuttini (1978) observed that areas perceptually expanded when textural characteristics were manipulated.

Because textural appearance can be considered in terms of space subparts' articulation, we study how textural properties are involved into perceptual areas estimation. In particular, we will consider the filled area phenomenon as related to a surface grain and therefore to textural statistics. To quantitatively investigate how filling an area affects its perceived size, we manipulate basic textural properties as *spatial frequency*, *microelements' number* and their *arrangement*, either in checkboard or random order. Differently from the investigations previously considered, those variables will be independently taken into account.

Experiment 1. In Expt. 1 we studied how the articulation in subparts of an area affects its perceived size. Keeping fixed the same test stimulus size, textures were filled with a variable number of microelements.

Method

Subjects. Three subjects (mean age = 29 years; SD = 5.8), naive to the purpose of all experiments, participated in the study. They had normal or corrected to normal visual acuity.
Stimuli. The stimuli were square figures entirely filled by microstructural square elements (Figure 1, panels a and b). To reduce possible three-dimensional effects casually occurring in textures filled by microelements – as figure-ground stratification – no overlapping between micropatterns was present. Consequently, illusory shrinkage or expansion resulting from amodal completion (for a review: Vezzani, 1999), were minimised. Mean luminance (69.5 cd/m2) was fixed for both test and control stimuli throughout all experiments. Control stimuli consisted in uniform grey squares. All test stimuli subparts were filled by achromatic colours, chosen within a three equidistant levels grey scale, from white to black (i.e.: 3, 69.5, 136 cd/m2). The subparts' number filling the square, and therefore its fundamental spatial frequency, were manipulated. Textures resulted composed by 2×2, 4×4, 8×8, 16×16, 32×32 square micropatterns, with a fundamental spatial frequency respectively of 0.1, 0.2, 0.4, 0.8, 1.6 cycles/deg (Figure 1, panels a and b). Micropatterns were arranged either as in a 'checkboard' (Figure 1, panel a) or in 'random' (Figure 1, panel b) order.
Procedure. The stimuli were presented in a dark room, at 57 cm from the screen, a Sony Trinitron Color E100P. A chin rest was used to stabilise the head; fixation was binocular. In each trial, test stimuli were presented on a blue background (69.5 cd/m^2), paired with a uniform grey square (the control stimulus). Spatial position of the two patterns were randomised inside either the left or right half part of the screen. To reduce evaluation biases, stimuli were presented using a set of constraints to avoid alignment of the squares corners and figures overlap (Figure 1, panel c). Subjects' task was to adjust the control stimulus to match the size of the test stimulus. Subjects were clearly instructed to gauge the square areas considering both their dimensions. Stimuli were observed in free vision, without time constraints. For each session, the control grey square size incremented or decremented inside a range of ±5% with respect to the test stimuli area. Eleven ordered equal steps, each of ±1% were employed. To avoid effects of order presentation, the series directions were randomised. Checkboard patterns were repeated 8 times. To minimise the possible biases resulting in accidental subparts' articulation, random patterns were presented 40 times. Experimental sessions order was randomised.

Results and discussion

Results are shown in Figure 1, for the aggregate (panel d) and individual (panel e) data. An illusory area increment was always found when squares were filled by subparts. The size increment in the aggregate data reached the highest value of 4.6% with the 8×8 checkboard pattern. Repeated measures ANOVA showed an effect of the filling microelements' number in perceiving areas ($F_{(4, 92)} = 83.01$; $p < .001$). However, the expansion proportionally increased with subparts' number and spatial frequency up to the 8×8 pattern, when the trend inverted. Checkboards presented a higher illusory effect than random patterns ($F_{(1, 23)} = 28.71$; $p < .001$).

Partial correlations between fundamental spatial frequency and perceived size, corrected for microelements' number ($R_{(717)} = .53$; $p < .001$), and between number of microelements and perceived size, corrected for fundamental spatial frequency ($R_{(717)} = -.52$; $p < .001$), indicated that the perceived expansion increased with spatial frequency and decreased with subparts' numerosity.

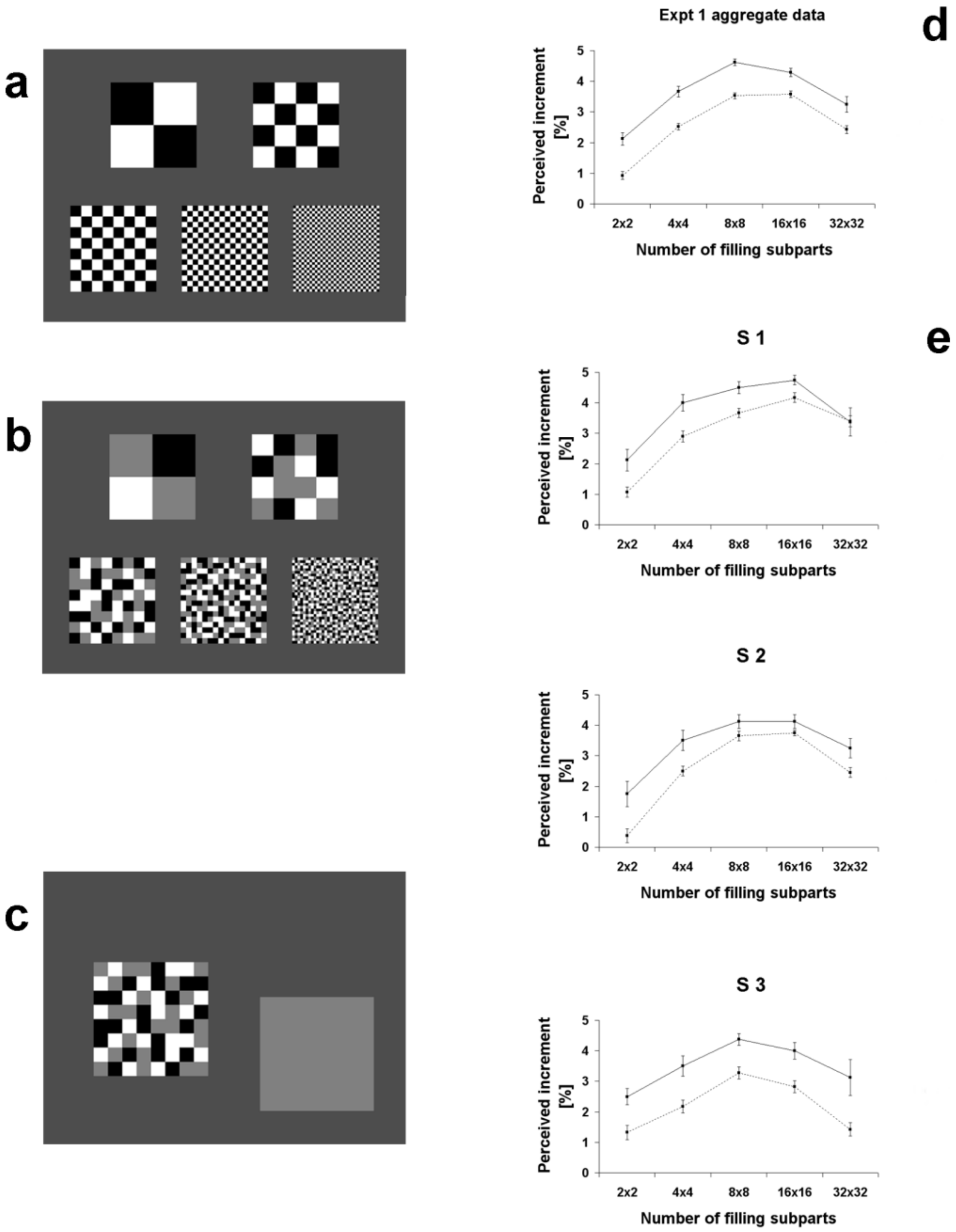

Figure 1. Stimuli of Expt. 1: regular and random patterns (panels a and b), a procedure trial (panel c), and the aggregate (panel d) and individual (panel e) results. Solid curves represent checkboards; dashed curves represent random patterns. Error bars indicate standard errors.

The effect of filling squares by microelements showed a typical inverted U curve. Partial correlations indicated that both spatial frequency and number of microelements significantly affect size perception. Increasing the fundamental spatial frequency enhances the illusory effect (positive correlation), whereas increasing the microelements' number reduces the area overestimation (negative correlation). In the first part of the curve it seems that the spatial frequency plays a major role and the illusion increases despite the microelements' increment. In the second part of the curve microelements' numerosity seems instead to prevail against spatial frequency. Thus, the illusory effect decreases, even if it does not disappear. The larger effect in checkboards, characterised by an ordered distribution of black and white subparts, suggests that the *texture arrangement* (checkboard vs. random) critically affects the illusion.

Experiment 2. In Expt. 1 both fundamental spatial frequency and the number of subparts covaried. To isolate the effect of those two variables, we manipulated them independently.

Method

Subjects. The same three subjects of Expt. 1 participated in this study.
Stimuli. Three sets of stimuli were adopted. The first group of stimuli aimed to verify the influence of fundamental spatial frequency on the illusory area enlargement. The stimuli were arranged either in checkboard or random order. Three values of fundamental spatial frequency were used: 0.4, 0.8 and 1.6 cycles/deg, while the 8×8 filling microelements' number was kept constant. Consequently, texture size resulted respectively of 9.6×9.6, 4.8×4.8 and 2.4×2.4 deg (Figure 2, panel a). The second group of stimuli tested the effect of subparts' numerosity. Textures with 8×8, 16×16 and 32×32 micropatterns were employed. In those patterns, the fundamental spatial frequency was kept constant at 1.6 cycles/deg. Texture size resulted respectively of 2.4×2.4, 4.8×4.8 and 9.6×9.6 deg (Figure 2, panel b).
Procedure. We used the method of constant stimuli. The control stimulus was compared in size with the textured stimulus and subjects reported which square appeared larger. The difference in control stimuli size ranged from -3 to 9 % (i.e. 13 equal steps of 1%), with respect to the textured stimuli. The experimental setting was the same described for Expt. 1. The twelve categories of stimuli represented in Figure 2 were matched 4 times with the 13 control stimulus size steps, resulting in a total of 520 trials.

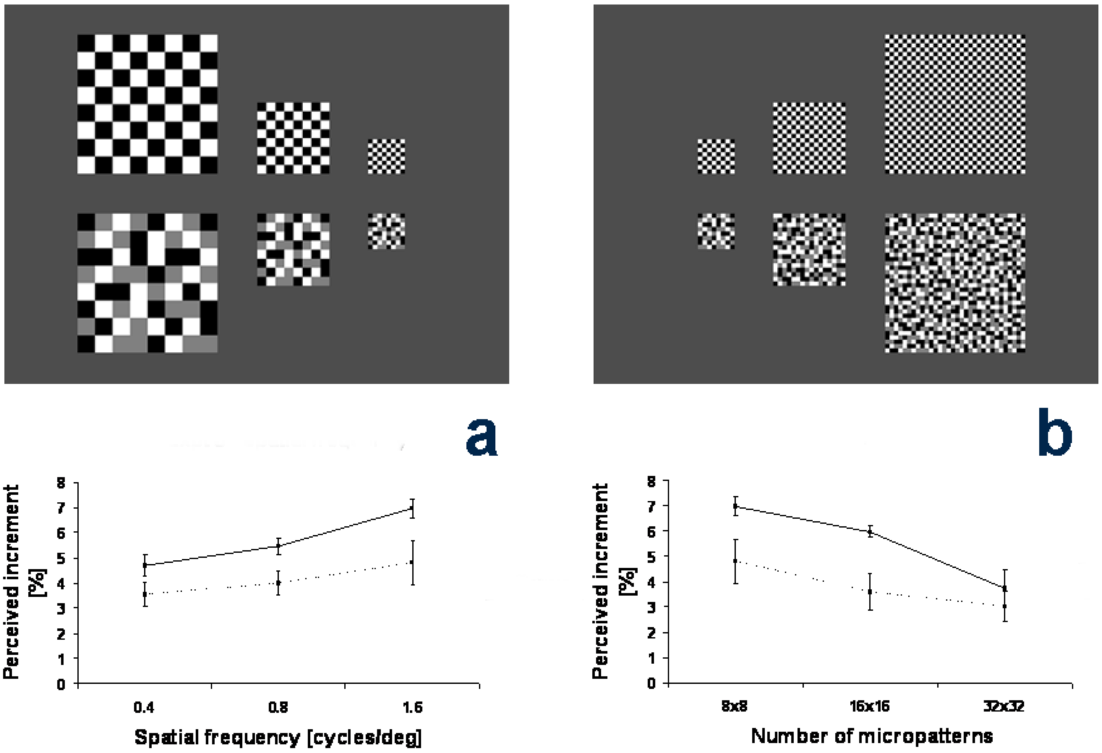

Figure 2. Stimuli of Expt. 2, distinguished for spatial frequency (panel a) and numerosity (panel b) conditions, and the respective results (mean thresholds). Solid curves represent checkboards; dashed curves represent random patterns. Error bars indicate standard errors.

Results and discussion

Individual data were fitted by a logistic function and individual thresholds, were calculated. Mean thresholds are depicted in Figure 2. An illusory area increment was always found when squares were filled by subparts. The size increment calculated for mean threshold reached the highest value of 6.96% with the 8×8, 1.6 cycles/deg checkboard pattern. Repeated measures ANOVAs shown that the illusory effect increased with fundamental spatial frequency ($F_{(2,\ 4)} = 22.62$; $p = .007$). As in Expt. 1, checkboards presented a larger perceived area than random patterns, although non significant ($F_{(1,\ 2)} = 15.02$; $p = .061$). Furthermore, the perceptual area enlargement decreased with microelements' numerosity ($F_{(2,\ 4)} = 24.06$; $p = .006$). As in Expts. 1, checkboards presented a larger perceived area than random patterns ($F_{(1,\ 2)} = 26.85$; $p = .035$).

Expt. 2 confirms that the illusory enlargement depends on spatial frequency, as indicated in Expt. 1. Whereas increasing the fundamental spatial frequency over 0.8 cycles/deg reduced the illusory effect in Expt. 1, over that value, in Expt. 2 – without varying the microelements' number – the effect still incremented together with fundamental spatial frequency. In Expt. 2 size covaries negatively with spatial frequency. However, Expt. 1 suggested that size did not play a crucial role in the illusion.

These results could shed some light about why the checkboard patterns always provided a higher illusory effect. Fundamental spatial frequency extraction would be, indeed, easier in checkboards than in random patterns, where the microelements arrangement is less organised. These data agree with the idea of a visual system working as a "spatial frequency analyzer" (Maffei & Fiorentini, 1973) and support the hypothesis that geometrical optical illusions of extent can be understood in terms of spatial filtering processes (Bulatov, Bertulis, & Mickiene, 1997).

Moreover, Expt. 2 confirms that the illusory enlargement is inversely proportional to the microelements' number, as indicated in Expt. 1. Although size covaries positively with numerosity, Expt. 1 suggested that square size variation should not be crucial for the illusion. These results seem consistent with the recent finding that numerosity is a basic property early processed by the visual system (Burr & Ross, 2008). It is nonetheless important to note that the reduction of the illusory effect when increasing subparts' numerosity can be understood also if one considers the textural appearance of a pattern densely filled by a great number of microelements. One can in fact argue that with the increase of subparts, the luminance variance inside a textured pattern decreases and the articulation in subparts becomes weaker.

In conclusion, this research shows how textural characteristics are responsible for the illusory enlargement of an area articulated in subparts. Basic statistical properties, early processed by the visual system, like spatial frequency and number of microelements, critically affect the size overestimation. These results agree with the idea that gauging the size of visual images is crucially affected by their textural statistics.

References

Adelson, E. N., & Bergen, J. R. (1991). The plenoptic function and the elements of early vision. In: M.S. Landy, & J.A. Movshon (Eds.), *Computational models of visual processing,* pp. 3-20. Cambridge (MA): MIT Press.

Ariely, D. (2001). Seeing sets: representation by statistical properties. *Psychological Science, 12*, 157-162.

Atchley, P., & Andersen, G. J. (1995). Discrimination of speed distributions: sensitivity to statistical properties. *Vision Research, 35*, 3131-3144.

Bazzeo, A., & Zanuttini, L. (1978). Illusory dilatation of square surfaces. *Perception, 7*, 467-471.

Bulatov, A., Bertulis, A., & Mickiene, L. (1997). Geometrical illusions: study and modelling. *Biological Cybernetics, 77*, 395-406.

Burr, D. C., & Ross, J. (2008). A visual sense of number. *Current Biology, 18*, 425-428.

Caelli, T., & Julesz, B. (1979). Psychophysical evidence for global feature processing in visual texture discrimination. *Journal of the Optical Society of America, 69*, 675-678.

Campbell, F. W., & Robson, J. G. (1968). Application of Fourier analysis to the visibility of grating. *Journal of Physiology, 197*, 551-566.

Dakin, S. C., & Watt, R. J. (1997). The computation of orientation statistics from visual texture. *Vision Research, 37*, 3181-3192.

Gibson, J. J. (1950). The perception of visual surfaces. *American Journal of Psychology, 63*, 367-384.

Giora, E., & Casco, C. (2007). Region- and edge-based configurational effects in texture segmentation. *Vision Research, 47*, 879-886.

Giora, E., & Gori, S. (in press). The perceptual expansion of a filled area depends on textural characteristics. *Vision Research*.

Haberman, J., & Whitney, D. (2009). Seeing the mean: ensemble coding for sets of faces. *Journal of Experimental Psychology, Human Perception and Performance, 35*, 718-734.

Haralick, R. M. (1979). Statistical and structural approaches to texture. *Proceedings of the IEEE, 67*, 786-804.

Julesz, B. (1965). Texture and visual perception. *Scientific American, 212*, 38-48.

Julesz, B. (1981). Textons, the elements of texture perception, and their interactions. *Nature, 290*, 91-97.

Karu, K., Jain, A. K., & Bolle, R. M. (1996). Is there any texture in the image? *Pattern Recognition, 29*, 1437-1446.

Kingdom, F. A., Hayes, A., & Field, D. J. (2001). Sensitivity to contrast histogram differences in synthetic wavelet-textures. *Vision Research, 41*, 585-598.

Maffei, L., & Fiorentini, A. (1973). The visual cortex as a spatial frequency analyzer. *Vision Research, 13*, 1255-1267.

Maffei, L., & Fiorentini, A. (1977). Spatial frequency rows in the striate visual cortex. *Vision Research, 17*, 257-264.

Marchant, A. P., & de Fockert, J. W. (2009). Priming by the mean representation of a set. *The Quarterly Journal of Experimental Psychology, 62*, 1889-1895.

Marr, D. (1982). *Vision*. San Francisco (CA): Freeman.

Morgan, M. J., Chubb, C., & Solomon, J. A. (2008). A ‘dipper’ function for texture discrimination based on orientation variance. *Journal of Vision, 8*(11):9, 1-8.

Navon, D. (1977). Forest before trees: the precedence of global features in visual perception. *Cognitive Psychology, 9*, 353-383.

Neisser, U. (1967). *Cognitive psychology*. New York (NY): Appleton-Century-Crofts.

Parkes, L., Lund, J., Angelucci, A., Solomon, J. A., & Morgan, M. J. (2001). Compulsory averaging of crowded orientation signals in human vision. *Nature Neuroscience, 4*, 739-744.

Verrillo, R. T., & Graeff, C. K. (1970). The influence of surface complexity on judgments of area. *Perception and Psychophysics, 7*, 289-290.

Vezzani, S. (1999). Shrinkage and expansion by amodal completion: a critical review. *Perception, 28*, 935-947.

Vicario, G. B. (2008). Optical-geometrical illusions: the nomenclature. *Gestalt Theory, 30*, 168-180.

Watamaniuk, S. N., & Duchon, A. (1992). The human visual system averages speeds information. *Vision Research, 32*, 931-942.

Zhang, J., & Tan, T. (2002). Brief review of invariant texture analysis methods. *Pattern Recognition, 35*, 735-747.