



Texture segregation shows only a very small lower-hemifield advantage

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Abstract

Possible hemifield differences in texture segregation were investigated for both simple (Fourier, linear) and complex (non-Fourier, second-order) texture channels. There was only a very small lower-field advantage for texture segregation, consistent with the notion that the major processing in texture segregation is quite low level, perhaps V1. Complex-channel tasks do not show larger hemifield asymmetries than do simple-channel tasks, which suggests that the processes in complex texture channels are not higher level than those in simple. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Differences in the abilities of lower versus upper, and of left versus right, visual hemifields have become of interest for a number of reasons. In areas V2 and above of extrastriate cortex, there is a large separation between the upper and lower hemifield representations (e.g. Horton & Hoyt, 1991). Also, as is well known, right and left visual hemifields project to the left and right hemispheres respectively. Since the distance between neurons imposes computational constraints by limiting the extent of their interconnections, these separate representations within the brain could set the stage for functional specializations in different hemifields—if such functional specializations were of any evolutionary advantage.

Upper-lower hemifield differences have been demonstrated in a number of visual tasks (e.g. Edgar & Smith, 1990; Previc, 1990; Berardi & Fiorentini, 1991; Christman, 1993; He, Cavanagh & Intrilligator, 1996; Rubin, Nakayama & Shapley, 1996; Gordon, Shapley, Patel, Pastagia & Truong, 1997), and one might suppose on the basis of anatomy that such tasks reveal relatively complicated processes primarily computed in V2 and above. Similarly, left-right lateralization has been

demonstrated in a number of visual tasks. A speculation that it occurs only for relatively high-level visual tasks (Moscovitch, 1979) has been supported by a small number of studies (see Kitterle, Christman & Hellige, 1990; Miossec, Kolinsky & Morais, 1993, and references therein).

We wished to discover the size of visual-hemifield differences (or non-differences) in segregation of the visual field into regions based on differences in texture. We were further interested in whether the hemifield differences might be greater for texture segregation done by complex (non-Fourier) channels than for that done by simple (linear) channels. The extra stage of processing in complex channels might occur at a higher level in the visual system than the simple channels (Wilson & Kim, 1994; Sutter & Graham, 1995). The texture-segregation task we used required the observer to identify the orientation of a rectangle of one texture that is embedded in a field of another (e.g. Nothdurft, 1985; Sutter & Graham, 1995). The control detection task used patterns containing only the rectangles of a single texture and required the observer to say whether or not there is any pattern present at all (as opposed to a steady gray field at the same mean luminance). We studied these tasks with three types of patterns we have used before.

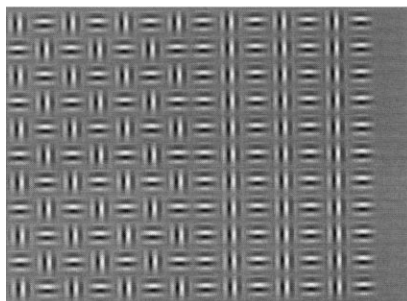
The first type of pattern requires segregation by complex texture channels, in particular by those having

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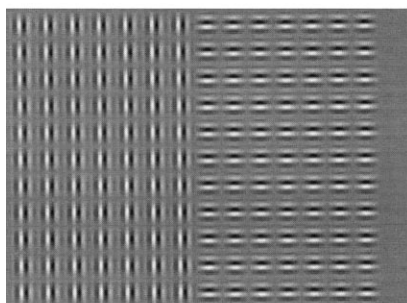
a first filter tuned to 8 c/deg and a second filter tuned to 1.5 c/deg. It consists of checkerboard vs. striped arrangements of Gabor patches of perpendicular orientations (e.g., top panel Fig. 1 here; Fig. 3 in Graham, Sutter & Venkatesan, 1993; and Fig. 2b in Sutter & Graham, 1995).

The second type requires segregation by simple texture channels tuned to relatively high spatial frequencies (8 c/deg). It consists of regions containing Gabor patches all of one orientation where the two different regions contain patches of perpendicular orientation (e.g., middle panel Fig. 1 here; Fig. 8 in Graham, Sutter & Venkatesan, 1993).

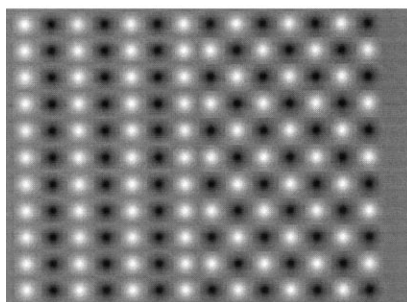
SAMPLES OF TEXTURES



Type 1



Type 2



Type 3

Fig. 1. Examples of the pair of textures used to make patterns of three types. Patterns of type one require segregation by complex channels; patterns of type two require segregation by simple channels of high spatial frequency; and patterns of type three require segregation by simple channels of low spatial frequency. In the segregation tasks, one member of each texture pair filled a rectangle embedded in a field of the other texture. In the detection tasks, one member of each texture pair filled a rectangle embedded in a blank gray field of the same mean luminance.

The third type requires segregation by simple texture channels tuned to relatively low spatial frequencies (1.5 c/deg). It consists of checkerboard vs. striped arrangements of Gaussian blobs (e.g., bottom panel Fig. 1 here; Fig. 2a in Sutter & Graham, 1995).

2. Details of methods and procedures

The full field contained 25×35 elements ($8.33 \times 11.67^\circ$), where each element was a Gabor patch or a Gaussian blob depending on pattern type. The long dimension was vertical in the upper/lower field experiments and horizontal in the left/right field experiments. The embedded rectangle contained 7×11 elements ($2.33 \times 3.67^\circ$) and could occur randomly in either a vertical or horizontal orientation and randomly in one of several positions on either side of the fixation point. Between the fixation point and the rectangle, there were always at least 2.5 rows or columns of background elements (0.85°). Each element was truncated to lie within a square of width 0.33° (16 pixels) so that neighboring elements did not overlap. The full width at half peak of the circular Gaussian envelope of either a Gabor-patch or Gaussian-blob element was 0.165° (8 pixels). The harmonic oscillation in the Gabor-patch elements was in sine phase with respect to the window (so that the space-average luminance was the same as the background luminance). Its spatial frequency was 8 c/deg (a period of six pixels) and its orientation either vertical or horizontal. The fundamental frequency of the element-arrangement patterns (pattern types one and three) was 1.5 c/deg. The patterns were presented for 100 ms with abrupt onsets and offsets. The observers were instructed to respond as quickly as possible without sacrificing accuracy. We studied a large range of contrasts in each kind of pattern. Each session contained only one of the three pattern types, but all other variables were randomized and counterbalanced within a session. For segregation, six sessions were run of each of the three pattern types (for each observer), where each session contained 384 trials, for a total of 2304 trials per pattern type per observer. For detection, 12 sessions were run of each of the three pattern types, where each session contained either 192 trials (pattern types one and two) or 60 trials (type three) for a total of 2304 trials (types one and two) or 960 trials (type three) per pattern type per observer. The whole set of sessions was repeated twice for each observer—once to study upper versus lower fields, and once to study left versus right fields. There were four observers, all of whom were between 17 and 22 years of age at the time of the study with normal or corrected-to-normal acuity and substantial practice in texture segregation tasks. All four of the observers are now right-handed but one of

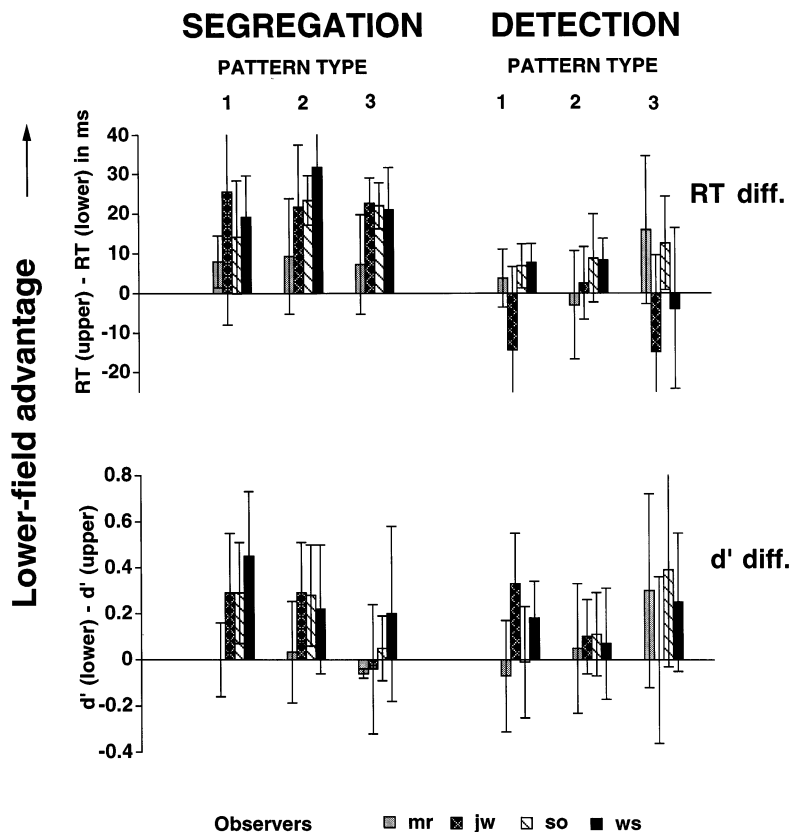


Fig. 2. Average d' (bottom panel of the figure) and reaction-time (top panel) differences between lower and upper hemifields in texture segregation (left half figure) and detection (right half figure) for four observers (different shading bars). There were three types of patterns as indicated by the numerals at the top. Patterns of type one require segregation by complex channels; patterns of type two require segregation by simple channels of high spatial frequency; and patterns of type three require segregation by simple channels of low spatial frequency. Vertical bars show \pm two standard errors of the mean. (Specifically they show \pm two standard errors of the mean, where the means and standard errors were computed across the n sessions for a single observer and a single pattern type. The value of n was 6 for segregation and 12 for detection.)

them (mr) reports being left-handed as a young child and has left-handed as well as right-handed relatives. Two are males (ws and jw), and two are females. Three of the four observers (all but jw) were tested and showed typical lower-field advantages in the Kaniza square paradigm of Rubin, Nakayama & Shapley (1996) or the paradigm of Gordon, Shapley, Patel, Pastagia & Truong (1997). Other aspects of the stimuli and procedure are like those in Sutter & Graham (1995).

Fig. 2 summarizes the differences between the upper and lower visual fields for each pattern type both in the segregation task (left half) and control detection task (right half). Differences between the reaction times (or d' values) in the upper and lower fields are shown in the top (or bottom) half of the figure. Differences favoring the lower field are plotted upward. Different observers are indicated by different colorings of the bar. Results here are shown averaged across all stimuli as we saw no substantial trends with contrast. The vertical bars show approximate 95% confidence limits. Other ways of assessing statistical significance lead to the same general conclusions. As Fig. 2 shows, there is an overall lower-

field advantage for segregation tasks that is particularly clear in reaction-time differences, but is quite small (19 ms and 0.17 d' units averaged over observer and pattern type). There is an even smaller (and only marginally significant) lower-field advantage for the control detection tasks (3 ms and 0.14 d' units averaged over observer and pattern type). The lower hemifield advantage occurs to the same extent for complex-channel segregation tasks (patterns of type one) as for simple-channel segregation tasks (patterns of type two and three).

This lower-field advantage is substantially smaller than that reported for a number of other visual tasks. Consider the illusory-contour tasks that originally interested us in this hemifield comparison (Rubin, Nakayama & Shapley, 1996). Most of those results were reported in terms of orientation thresholds which cannot be directly compared to the results here. But examples of psychometric functions are shown for one observer (Fig. 4, left panels in Rubin, Nakayama & Shapley, 1996) and can be approximately inferred for others. Using those functions to estimate the d' difference between performances in the two fields gives an average lower-field advantage of greater than 0.9 d'

units, far larger than the difference we found for texture segregation. Also larger lower-field advantages have been reported in tasks requiring spatial attention (He, Cavanagh & Intrilligator, 1996), phase discrimination (Berardi & Fiorentini, 1991), and global-local tasks (Christman, 1993).

The differences between the left and right visual fields (not shown) are even smaller than those between the lower and upper fields shown in Fig. 2. Averaged over subjects and tasks, there was a very small right-field (left-hemisphere) advantage for segregation tasks (12 ms and 0.03 d' units) while that for detection tasks was even smaller and in the opposite direction (4 ms and 0.02 d' units left-field, right-hemisphere advantage). Since our observers always used the right hand which introduces a few milliseconds of right-field advantage (e.g. Brysbaert, 1994), the size of these effects should perhaps be adjusted accordingly (producing a somewhat smaller right-field advantage for segregation and a somewhat larger left-field advantage for detection), but in any case they are small.

These left-right hemifield differences are smaller than most results reported as showing lateralization in visual tasks (e.g., spatial-frequency discrimination in Kitterle & Selig, 1991, phase discrimination in Berardi & Fiorentini, 1991). However, left-right differences are not always found in visual tasks. Of particular relevance here, in the illusory-contour study that found substantial lower-field advantage, they briefly reported finding no left-right difference (Rubin, Nakayama & Shapley, 1996).

Our intention was to study possible hemifield differences in texture-segregation tasks of the type we have been using for some time, tasks chosen in order to study hypothetical segregation processes that initially parse the visual scene into regions. In these tasks, we do not use a post-stimulus mask, nor place any strong demands on attention. (There are some implicit demands imposed by requiring accurate quick performance with feedback as to correctness.) A number of the situations in which strong hemifield differences (left/right or upper/lower) have been reported involve post-stimulus masking (e.g. Rubin, Nakayama & Shapley, 1996; Gordon, Shapley, Patel, Pastagia & Truong, 1997). An effective post-stimulus mask, by its nature, may lead the observer to pay close attention to distinguish the perceptual event on which the response is to be based from the subsequent perceptual effect of the post-stimulus mask. Other studies involve an explicit manipulation of attention (e.g. He, Cavanagh & Intrilligator, 1996; Hubner, 1997). Thus it seems to us quite possible that introducing an effective patterned post-stimulus mask or putting strong demands on attention in some other way (e.g. going back and forth between a segregation task on some trials and a local-element discrimination on others) might produce larger differ-

ences in our tasks. In our view, however, these differences would be due to high-level processing that was quite distinct from the region-segregation processes we wanted to study with this task.

Thus we conclude that the primary determinants of responses in these texture-segregation tasks are not differentiated by hemifield. These processes may, therefore, be rather low level in the cortex, perhaps V1. This is consistent with physiological evidence showing that responses capable of underlying segregation occur in V1 (Bach & Meigen, 1992, 1997; Lamme, van Dijk & Spekrijse, 1993; Lamme, 1995; Purpura, Victor, & Katz, 1994; Victor & Conte, 1989). These conclusions should be held tentatively, however, since, based on current knowledge, the possibility remains that the processing in certain higher-level areas (e.g. V4) does not show hemifield asymmetries although processing in other areas (e.g. MT) does. Until we know more about which visual tasks do and which do not show such asymmetries, we cannot be sure. To look at these results from a slightly different perspective—whatever evolutionary pressure may exist for hemifield specialization does not seem to apply strongly to segmentation of the visual scene based on differences in visual texture.

The small but definite lower-hemifield asymmetry suggests some higher-level processes do contribute to these texture segregation tasks although less than they contribute to the illusory-contour tasks of Rubin, Nakayama & Shapley (1996). These higher-level processes could involve, for example, the allocation of attention and/or the formation of long-distance contours, short-range grouping, or grouping regions of similar structures. There is insufficient evidence at present to distinguish among these possibilities.

Whatever these higher-level processes are, however, they do not seem to contribute more to complex-channel tasks than to simple-channel tasks (although a small-enough difference could not be ruled out, of course). When discussing mechanisms for motion perception, Wilson & Kim (1994) suggested that the second stage of non-Fourier (complex) motion channels may be in V2 while the first stage and also the simple mechanisms are in V1. The results here, however, suggest that, for texture processing if not for motion, the second stage of complex channels is *not* higher-level than the simple channels (at least not high enough to cause further lower-field advantage and therefore presumably not as high as V2).

Note added in press

Recently we learned that Hofmann and Hallett (1993) reported a lower hemifield advantage for texture segregation. Their textures are quite different from ours, and their reported advantage seems somewhat larger than the ones we found. Comparing these two situations may be informative.

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References

- Bach, M., & Meigen, T. (1992). Electrophysiological correlates of texture-segmentation in human visual evoked potential. *Vision Research*, *32*, 417–424.
- Bach, M., & Meigen, T. (1997). Similar electrophysiological correlates of texture segregation induced by luminance, orientation, motion and stereo. *Vision Research*, *37*, 1409–1414.
- Berardi, N., & Fiorentini, A. (1991). Visual field asymmetries in pattern discrimination: A sign of asymmetry in cortical visual field representation? *Vision Research*, *31*, 831–836.
- Brysbaert, M. (1994). Behavioral estimates of interhemispheric transmission time and the signal detection method: A reappraisal. *Perception and Psychophysics*, *56*, 479–490.
- Christman, S. E. (1993). Local-global processing in the upper versus lower visual fields. *Bulletin of the Psychonomic Society*, *31*, 275–278.
- Edgar, G. K., & Smith, A. T. (1990). Hemifield differences in perceived spatial frequency. *Perception*, *19*, 759–766.
- Gordon, J., Shapley, R., Patel, P., Pastagia, J., & Truong, C. (1997). The lower visual field is better than the upper visual field at red/green recognition. *Investigative Ophthalmology and Visual Science*, *38*(4), S898.
- Graham, N., Sutter, A., & Venkatesan, C. (1993). Spatial-frequency- and orientation-selectivity of simple and complex channels in region segregation. *Vision Research*, *33*, 1893–1911.
- He, S., Cavanagh, P., & Intrilligator, J. (1996). Attentional resolution and the local of visual awareness. *Nature*, *383*, 334–337.
- Hofmann, M. I., & Hallett, P. E. (1993). Texture segregation based on two-dimensional relative phase differences in composite sine-wave grating patterns. *Vision Research*, *33*, 221–234.
- Horton, J. C., & Hoyt, W. F. (1991). Quadrantic Visual Field Defects. *Brain*, *114*, 1703–1718.
- Hubner, R. (1997). The effect of spatial frequency on global precedence and hemispheric differences. *Perception and Psychophysics*, *59*, 187–201.
- Kitterle, F. L., Christman, S., & Hellige, J. B. (1990). Hemispheric differences are found in the identification, but not the detection of low versus high spatial frequencies. *Perception and Psychophysics*, *48*, 297–306.
- Kitterle, F. L., & Selig, L. M. (1991). Visual field effects in the discrimination of sine-wave gratings. *Perception & Psychophysics*, *50*, 15–18.
- Lamme, V. A. F. (1995). The Neurophysiology of Figure-Ground Segregation in Primary Visual Cortex. *Journal of Neuroscience*, *15*, 1605–1615.
- Lamme, V. A. F., van Dijk, B. W., & Spekreijse, H. (1993). Organization of texture segregation processing in primate visual cortex. *Visual Neuroscience*, *10*, 781–790.
- Miossec, Y., Kolinsky, R., & Morais, J. (1993). Illusory conjunctions and the cerebral hemispheres. *Perception and Psychophysics*, *54*, 604–616.
- Moscovitch, M. (1979). Information processing in the cerebral hemispheres. In M. S. Gazzaniga, *Handbook of behavioral neurobiology: 2. Neuropsychology*. New York, NY: Plenum, 379–446.
- Nothdurft, H. C. (1985). Orientation sensitivity and texture segmentation in patterns with different line orientation. *Vision Research*, *25*, 551–560.
- Previc, F. (1990). Functional specialization in the lower and upper visual fields in humans: Its ecological origins and neurophysiological implications. *Behavioral and Brain Sciences*, *13*, 519–575.
- Purpura, K. P., Victor, J. D., & Katz, E. (1994). Striate cortex extracts higher-order spatial correlations from visual textures. *Proceedings of the National Academy of Sciences USA*, *91*, 8482–8486.
- Rico, M., Graham, N., Offen, S., & Scott, W. (1997). Texture segregation in lower versus upper visual hemifields. *Investigative Ophthalmology and Visual Science*, *38*(4), S639.
- Rubin, N., Nakayama, K., & Shapley, R. (1996). Enhanced perception of illusory contours in the lower versus upper visual hemifields. *Science*, *271*, 651–653.
- Sutter, A. K., & Graham, N. (1995). Investigating simple and complex mechanisms in texture segregation using the speed-accuracy trade-off method. *Vision Research*, *35*, 2825–2843.
- Victor, J. D., & Conte, M. (1989). Cortical interactions in texture processing: scale and dynamics. *Visual Neuroscience*, *2*, 297–313.
- Wilson, H. R., & Kim, J. (1994). Perceived motion in the vector sum direction. *Vision Research*, *34*, 1835–1842.