Visual Field Anisotropy for Perceiving Shape from Shading and Shape from Edges

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Two experiments were designed to examine the existence of lower versus upper visual field anisotropy in form perception based on shading and edge-based information. In the experiments, subjects were asked to judge the visual property of the stimulus defined by shading or edge. The results demonstrated that the lower visual field is specialized for the processing of shading information, whereas the upper field is specialized for the processing of edge-based information. These findings are consistent with Previc's (1990) hypothesis that the processing of optically degraded images is linked to a peripersonal visual system which is biased to the lower visual field, while an extrapersonal visual system, which is biased toward the upper visual field, is used for the processing of details of form.

KEYWORDS: visual field, anisotropy, shading, edge

Introduction

In a recent theoretical review, Previc (1990) proposed the upper and lower visual fields in humans are functionally specialized for far (extrapersonal space) and near (peripersonal space) vision, respectively. Previc argued that the upper visual field (UVF) is linked to the "linear/local" perceptual mechanism which is related to visual search and scanning directed toward extrapersonal space, while the lower visual field (LVF) has become specialized for the "nonlinear/global" processing which is responsible for the perception of optically degraded and diplopic images in near vision.

Previc defines the terms linear/local and nonlinear/global in accordance with their neurophysiological usage (Enroth-Cugell and Robson, 1966). For example, neurons in the linear/local system are better at detecting the precise spatial profile of a luminance gradient and this system would transmit precise spatiotemporal phase information. Conversely, neurons in the nonlinear/global system might respond to the optically degraded visual input and therefore this system would be more adept at processing transient, low-contrast information.

If there were linear/local versus nonlinear/global differences in visual information processing between upper and lower visual fields as Previc postulates, there should be differences in the processing of local versus global properties of the stimuli presented along the vertical meridian of the visual field. With regard to this prediction, Christman (1993) found that the upper and lower visual fields are differentially specialized for the processing of local-global stimuli consisting of a large letter made up in outline from small letters (similar to the hierarchically structured compound stimuli employed by Navon, 1977). When the stimulus display contained the target defined as the local level letter, performance in the UVF was superior to that in the LVF, whereas when the target was present at the global level, performance was better in the LVF than that in the UVF (see also Lamb and Yund, 1996). However, there is only a little evidence to demonstrate upper-lower visual field differences in terms of local-global or linear-nonlinear processing.

In the present study, we attempted to find further evidence for the specialization of the UVF versus LVF for the processing of linear/local versus nonlinear/global information. In this study, we focused on the two sources of visual information which are used to perceive the three-dimensional structure of objects as an analog of local-global distinction of visual perception. One source of information is edge and the other is shading.

Edge is the discontinuous intensity variations such as luminance and depth discontinuities that is found at the boundaries of an object. A number of studies suggest that the first stage of visual perception should involve edge detection and therefore edge-based representation is one of the important visual inputs for object recognition (e.g., Biederman, 1987; Marr and Hildreth, 1980).

Shading is the luminance gradients across part of an image that conveys an impression of solidity and depth of objects. The pattern of shading depends on various factors such as direction of illumination, distance from a light source, type of the curvature and reflectance of the object's surface, and specifically, orientation of the surface relative to the viewer (Ramachandran, 1988). Furthermore, perception of the visual information defined by shading (shape from shading) is assumed to be predominantly a head-centric mechanism (Howard, Bergström, and Ohmi, 1990; Wenderoth and Hickey, 1993).

Previc (1990) argued that cells in a nonlinear/global perception mechanism would be adept at processing optically degraded, low-contrast information, while a linear/local perceptual system would transmit contour-depen-

dent, precise spatiotemporal phase information. According to this argument, one should expect that perception of shading information may dominate in the LVF which is tied to a nonlinear/global perception mechanism, because the shading gradients have luminance intensity at relatively low spatial frequencies. While one could assume that perception of visual objects defined by edges might be superior in the UVF because of the presence of a high contrast contour-based information with abrupt luminance changes. However, no direct empirical evidence is presented regarding the functional differences between upper and lower visual fields for the processing of visual information defined by edge versus shading. The purpose of the present study was to examine the upper versus lower visual fields differences in the processing of edge-versus shading-based visual information.

Experiment 1

Method

Subjects. Seven subjects participated in the present experiment. All subjects had normal or corrected-to-normal vision, and they were not familiar with the purpose of the experiment.

Apparatus, stimuli, and design. Stimulus presentation and data acquisition were controlled by an AV tachistoscope (Iwatsu Isel: IS-701D) connected with a Macintosh Centris 650 microcomputer. The AV tachistoscope displayed a visual pattern on a CRT monitor (21-in.) with 10-ms accuracy, using a raster scan method. Subjects made responses with button box attached to the AV tachistoscope and response latencies were measured with 1-ms accuracy. The stimuli were displayed on the screen, placed approximately 57 cm from the eyes of the subject. All stimuli were presented on a gray background (18.2×18.2 deg, 9.8 cd/m^2). A small plus sign ("+" , 0.5×0.5 deg of visual angle) presented in the center of the screen served as a fixation point.

Two within-subjects factors determined the appearance of stimulus displays: visual field (upper visual field: UVF or lower visual field: LVF) and stimulus type (shading or edge). The visual field factor specified the location of stimulus item within the display. In the UVF and LVF conditions, the stimulus appeared above or below the fixation point, respectively. The stimulus subtended 1.0 deg of visual angle, and the center of each item was located 5.9 deg above or below from a fixation point. The stimulus type factor specified the identity of the stimulus item. Figure 1 shows the two types of stimulus items used in the experiment: (A) shading: linearly shaded circles in which the implied light source was either from upper left or from upper right of each item. The side of light source varied randomly from trial to trial, but each of the two lighting sides appeared on an equal proportion of trials. The lightest and darkest segments of the shading item had luminances of 68.5 cd/m^2 and 0.9 cd/m^2 , respectively. (B) edge: discs with a step change in luminance which have the same luminance polarity differences as the shading items.

Procedure. Viewing distance, fixed by an adjustable head-and-chin-rest, was approximately 57 cm. The subject's task consisted of a two-alternative forced choice identification task in which subjects were asked to determine whether the lightest region (or white region for the edge stimuli) of the stimulus item was "upper left" or "upper right" side by pressing a button corresponding to the "upper left" with the left index finger or a button corresponding to the "upper right" with the right index finger. Subjects were instructed to make their responses as quickly as possible while keeping errors as few as possible. Response time (RT) was measured from stimulus onset to response emission.

Each trial began with the presentation of the central fixation point and a prompt to press a button when ready to continue. A fixation point was always visible and the subjects were required to fixate it throughout each trial. When ready, the subject pressed a button initiating the trial sequence. Following a 1000-ms fixation interval af-

Fig. 1 Examples of the two types of stimuli used in Experiment 1: (A) shading; (B) edge.

ter the button was pressed, the stimulus item was presented on one of the two possible locations: above or below of the fixation point. The stimulus display remained visible until a response was made or 2000 ms had elapsed.

The subjects were individually tested in two experimental sessions, subdivided into 2 blocks separated by a 10-min. rest. In one of the sessions the shading items were employed, whereas in the other the edge items were employed. The order of stimulus type condition was counterbalanced across subjects. In one experimental session, each subject underwent 144 trials per session, of which 72 were UVF and 72 were LVF trials. In addition, there were 40 catch trials in which a fixation point was replaced to "O" or "Q" (0.5×0.5 deg) for 40 ms before the onset of the stimulus item, and the subject had to report which of the two letters appeared, as well as the response to the stimulus item. Each subject received 40 practice trials prior to the start of each of the two experimental sessions. The data on practice trials and catch trials were not included in data analysis. Thus the entire experiment contained 448 trials (288 experimental trials, 80 catch trials and 80 practice trials).

Results and discussion

Mean RTs and percent errors are shown in Figure 2. Trials with correct responses faster than 160 ms or slower than 1500 ms (0.69% of trials), as well as incorrect responses, were excluded from the RT analysis.

A two-way analysis of variance (ANOVA) with repeated measures was performed with visual field (UVF vs. LVF) and stimulus type (shading vs. edge) as independent variables. This analysis revealed a significant interaction between visual field and stimulus type [$F(1, 6) = 19.20, p < .005$], with shorter RTs for the LVF (386 ms) than for the UVF (403 ms) only for the shading stimuli, but not for the edge stimuli (372 and 376 ms, respectively). Analysis of percent errors revealed no significant effects.

These results provide partial support for the assumption mentioned above that the lower and upper visual fields are differentially specialized for the processing of shading and edge-based visual information. When the stimulus was defined by shading information, it was identified faster in the lower than in the upper visual field. On the other hand, when the stimulus was defined by edge-based information, there was no difference between the two visual fields.

The fact that a UVF advantage was not obtained with the edge stimuli limits the generalizability of the current results. The present data did not assure any definitive explanation for the lack of this effect. One possibility is that due to a ceiling performance in the edge task, therefore the current experiment lacked sufficient power to detect a upper versus lower visual field anisotropy in the RT data. This speculation may be supported by the fact that RTs for the edge stimuli collapsed over visual fields tended to be shorter than those for the shading stimuli (edge < shading for 5/7 subjects), although a comparison of the RTs for the shading versus edge stimuli (374 and 394 ms, respectively) failed to yield a significant difference.

Since the display was present until the subject responded, it is likely that eye movements took place. We believe that the subjects in this experiment tend to maintain their fixation on the center of the screen while the display is present, because error ratio for reporting a fixation letter ("O" or "Q") on catch trials were very low (1.1 and 1.4% for the shading and edge stimuli, respectively). There was no guarantee, however, that the subjects did not make eye movements. To disentangle this possibility, in Experiment 2 display duration was shortened to

Fig. 2 Mean reaction times (in milliseconds) and percent errors (in parentheses) in Experiment 1. Error bars show standard errors of the means.

prevent eye movements. Moreover, to explore to what extent our findings were general, in the following experiment we used a different paradigm of stimulus presentation: a detection task in which arrays of stimulus elements were tachistoscopically presented, and subjects were required to determine whether all of the elements were the same or whether there was an odd element in either the upper or lower visual field.

Experiment 2

Method

Subjects. Three subjects participated in the present experiment. All subjects were well-practiced in psychophysical experiments and had normal or corrected-to-normal vision. One of the subject was of the second author (M.S.), while two others (K.K. and T.U.) were not familiar with the purpose of the experiment.

Apparatus. These were identical to those in Experiment 1.

Stimuli. A trial consisted of three frames: the fixation, stimulus and mask display.

The fixation display contained only a central fixation point ("+", 0.5×0.5 deg) against a gray background (18.2×18.2 deg, 9.8 cd/m^2).

The stimulus display consisted of one of the two types of texture elements: (A) shading and (B) edge (Figures 3(A) and 3(B)). Each element of the texture stimulus display was presented on a square grid of 8 rows $\times$ 8 columns, and it was randomly jittered in its grid location by ± 0.4 deg to prevent judgments based on item colinearity. The size and construction of each element in the texture display were the same as those of the stimulus items in Experiment 1, with the exception that lighting (the side of the lightest region for the shading stimuli, or white region for the edge stimuli) was situated in the lower left, lower right, upper left, or upper right of each ele-

Fig. 3 Examples of the stimulus and mask displays: (A) stimulus display for the shading condition (LS target in the UVF); (B) stimulus display for the edge condition (HS target in the LVF); (C) and (D) sample mask displays in the shading and edge conditions, respectively. The dotted circles in Figure 3(A) show the possible target locations in the array and were not present in the actual stimulus display.

ment. Depending on the direction of lighting, the impression of shading is either of a top- or bottom-lit object. For this reason, we referred to elements with “upper left” and “upper right” lighting region (white region for the edge stimuli) as “low shadow: LS” elements, and elements with “lower left” and “lower right” lighting region (or white region) as “high shadow: HS” elements. Since several studies using the paradigm of visual search have shown that it is much easier to detect a HS target against a background of LS distractors than vice versa (Braun, 1993; Kleffner and Ramachandran, 1992; Ramachandran, 1988), it seemed probable that the search asymmetry is seen under the present condition as well. Taking this possibility into account, the data for HS and LS elements were analyzed separately. The target element differed from the distractors by a 180 deg rotation in the image plane. In one case, the target was HS element and the background elements were of LS distractors. In the other case, their roles were reversed. In a trial, the target element appeared in one of the four positions in the second (UVF condition) or seventh (LVF condition) row, at approximately 6.0–7.0 deg eccentricity (see Figure 3(A)). The target element was equally likely to appear in each of these locations of the target rows.

The mask display consisted of a mixture of texture elements with a top-, bottom-, left-, and right-lit region (top-, bottom-, left-, and right-white region for the edge stimuli). Sample mask displays are shown in Figures 3(C) and 3(D). For both the two stimulus type conditions, four variations of the mask display were formed and one of the four mask displays was chosen randomly for every trial.

Design and procedure. The experimental design included three within-subjects factors: visual field (UVF, LVF, or absent), stimulus type (shading or edge) and direction of lighting (HS or LS). Each subject participated in four experimental sessions: shading condition with LS, HS elements, and edge condition with LS, HS elements. The order of the sessions was counterbalanced across the subjects. The subjects completed two experimental blocks for each session. Each block of the experiment consisted of 144 trials (48 trials from each of three visual field conditions) presented in random order. Two third of the trials contained one target element (UVF and LVF conditions), and the remaining contained no target elements (the absent condition). The subjects were well practiced and achieved stable performance during several hundred practice trials prior to each experiment.

Viewing distance, fixed by a head-and-chin-rest, was approximately 57 cm. The subject’s task was to determine whether the target element appeared in the top half of the display, in the bottom half of the display, or did not appear in the display by pressing a button corresponding to these three categories. The subjects were instructed that their responses were not being timed, and to be as accurate as possible.

Each trial began with the presentation of a central fixation point and a prompt to press a button when ready to continue. The fixation point was always visible at the center of the display screen, and the subjects were asked to fixate it throughout each trial. When ready, the subject pressed a button initiating the trial. The trial began with the presentation of the fixation display for a varying interval (160, 200, 240, or 280 ms, chosen randomly for every trial), followed by the stimulus display (100 ms for the shading stimuli, or 180 ms for the edge stimuli), which was replaced by a second fixation interval (160 ms), and then by a mask display (90 ms). An informal stair-casing procedure was used to find the maximal exposure duration for each of the two stimulus types, limiting all of the three subjects to 90% accuracy in the detection of the target element without the mask display. This procedure ensured that stimulus patterns were available as long as necessary for the task to be performed, and not longer. The randomly variable fixation interval at the beginning of the trial prevented planned saccades, and the short exposure duration of the stimulus display prevented directed eye movements while the display was on (Rayner, Slowiaczek, Clifton, and Bertera, 1983). The mask limited visible persistence of the stimulus display.

Results and discussion

Figure 4 shows the percent correct scores for shading stimuli for each of the three subjects, and Figure 5 shows the results for edge stimuli. Because the data were categorical and did not meet the assumptions of parametric analyses, chi-squared analyses (using Yates’ correction where appropriate) were used to examine UVF-LVF differences for the two types of stimulus patterns (shading and edge) separately. The rates of correct rejection (a correct response in the absent condition) were much better than chance—more than 70% across three subjects, stimulus types and directions of lighting.

Shading. There were more correct trials in the LVF condition than in the UVF for LS target elements (M.S.: $\chi^2(1) = 6.90, p < .001$; K.K.: $\chi^2(1) = 28.56, p < .0001$; T.U.: $\chi^2(1) = 6.77, p < .001$), whereas there was no such difference for HS stimuli with the exception of M.S.’s performance (M.S.: $\chi^2(1) = 5.660, p < .05$; K.K.: $\chi^2(1) = 2.64, n.s.$; T.U.: $\chi^2(1) = 0.67, n.s.$).

Edge. In contrast to the result of the shading target, LS target elements of the edge stimulus were better detected in the UVF condition than in the LVF (M.S.: $\chi^2(1) = 5.45, p < .05$; K.K.: $\chi^2(1) = 9.24, p < .005$; T.U.: $\chi^2(1) = 15.81, p < .0001$). However, as in the result of shading pattern, there was no visual field difference for the detecting HS elements with the exception of T.U.’s performance (M.S.: $\chi^2(1) = 0.00, n.s.$; K.K.: $\chi^2(1) = 1.99, n.s.$; T.U.: $\chi^2(1) = 6.53, p < .05$).

The results of Experiment 2, in which stimulus presentation was transient and masked, replicated findings of

Fig. 4 The percent correct for the shading stimuli for each of the subjects in Experiment 2.

Fig. 5 The percent correct for the edge stimuli for each of the subjects in Experiment 2.

Experiment 1 that demonstrated upper versus lower visual field differences in the processing of shading and edge-based visual information. Once again, a significant lower versus upper visual field advantage was observed in the detection of stimuli defined by the direction of shading gradients. Furthermore, in contrast to Experiment 1, an upper versus lower visual field advantage was observed in the processing of edge information. These findings suggest that such visual field differences may not be due to eye movements, but rather it may be the result of the functional specialization in the upper and lower visual fields. However, it should be pointed out that the occurrence of a lower visual field advantage in the processing of shading information was dependent on the direction of lighting: for detecting HS target in which a dark region is at the top of the target element, there was no visual field differences. This result is consistent with several findings that demonstrated a similar search asymmetry in shape from shading (Braun, 1993, Kleffner and Ramachandran, 1992; Ramachandran, 1988). This seems to suggest that HS and LS targets generate signals of different amplitude and the subjects find HS target easier to detect than LS target. Indeed, all the subjects exhibited relatively low error rates (less than 30%) for the detection of HS target across conditions in both the shading and edge tasks. Though the data of the present experiment could not shed light on the reason for such an asymmetry, we may speculate that HS elements are encoded as a salient or unique feature and this causes efficient detection performance of HS target. It may be possible to predict a large effect size even for HS target by using more sensitive measures and a more powerful experimental manipulation (i.e., shortening the stimulus duration and/or the target-mask interval).

General discussion

Two experiments were conducted to examine the upper versus lower visual field differences in the processing of edge- versus shading-based visual information. Experiment 1 revealed the existence of a LVF advantage in the processing of the stimulus defined by the direction of shading. Experiment 2 replicated this result while ex-

cluding the possibility of an explanation based on eye-movement. In addition, it also demonstrated that detection of an edge-based target was more accurate in the upper visual field. These findings are consistent with Previc's (1990) theoretical model on the functional specialization in the UVF and LVF in the human visual system: the processing of shading information in nonlinear/global visual system is biased predominantly toward the LVF, in contrast to the bias of linear/local perceptual mechanism used in the processing of edge information toward the UVF.

Recent studies have demonstrated the existence of the upper-lower visual field differences in many aspects of visual information processing. With regard to hemifield difference in nonlinear/global perception, several studies have reported a LVF advantage in the processing of low spatial frequencies (Murray, MacCana, and Kulikowski, 1983; Rijdsdijk, Kroon, and van der Wildt, 1980), although the evidence is less consistent regarding upper-lower differences in processing for high frequency components. Similarly, Berardi and Fiorentini (1991) reported a LVF advantage in a spatial phase discrimination task (which involve the precise global localization of visual stimuli, see also Edgar and Smith, 1990). More recently, Rubin, Nakayama, and Shapley (1996) found that the perception of illusory contours, which involves a fundamentally nonlinear set of computations, was superior in the LVF. With regard to linear/local perception, conversely, studies of visual search have yielded evidence that the ability to find a specified visual pattern defined by local features (e.g., color, orientation, and shape) was much better when it was presented in the UVF (Yund, Efron, and Nichols, 1990; Previc and Blume, 1993). Although the exact relation of the recent findings to the present results is not clear, these findings do not contradict Previc's hypothesis that predicted a special role of the UVF and LVF in linear/local and nonlinear/global perceptual mechanisms, respectively.

If there are linear/local versus nonlinear/global differences in visual information processing between upper and lower visual fields, then one might expect that cells with linear receptive field properties should predominate in UVF, whereas those with nonlinear receptive field properties should predominate in LVF. Previc (1990) hypothesized that processing differences between the UVF and LVF might be associated with the functional segregation of the two distinct divisions of the primate visual system, extending from the retina to the higher cortical areas in extrastriate visual cortex (Felleman and Van Essen, 1991).

Unfortunately, there is little evidence of a functional asymmetry on the neuronal response properties between upper and lower visual fields in early stages of visual processing (Previc, 1990). It may be possible, however, that the differential visual field specialization in the processing of edge and shading information is related to the functional specialization of higher visual areas: the ventral (occipito-temporal) and dorsal (occipito-parietal) visual pathways (Milner and Goodale, 1995; Ungerleider and Mishkin, 1982). In extrastriate cortical areas (V2 and higher) of primates, the representations of upper and lower visual space project preferentially to the ventral and dorsal visual pathways, respectively (Felleman and van Essen, 1991; Zeki, 1969). The presence of these disproportionate representations of the hemifields may be a possible basis for the links between the upper and lower visual field differences and the ventral and dorsal cortical dichotomy. This is further supported by the fact that the patient, who has deficits in various aspects of form perception owing to a lesion in the ventral pathway, could recover shape from shading but not from edges (Humphrey, Symons, Herbert, and Goodale, 1996). Although quite tentative, Humphrey et al.'s observation suggests that the neural mechanisms mediating the perception of shading information are distinct from those mediating the perception of edge information. But since there is very little evidence of the neural correlates that compute the extraction of shape from shading, it is premature to offer any conclusions regarding visual field differences in linear/local and nonlinear/global processing at this time.

Another possible account of the data is that the anisotropy across the upper and lower visual fields does not reflect processing differences arising from any underlying functional specialization of the visual pathways for processing the specific type of stimulus, but may instead reflect the differential speed in attentional scanning and/or the natural orienting biases of visual attention (Efron and Yund, 1996; Previc, 1996). However, several studies have reported that shading information as well as edge information are processed in the early stages of visual processing that occurs prior to attentional processing (Kleffner and Ramachandran, 1992). Thus, it is not clear as to the extent to which visual field differences in the perception of shading and edge information reflect visual field differences in attentional processing, and further work is needed to clarify the relative contributions of attentional factors to the upper versus lower visual field anisotropy.

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REFERENCES

- [1] Berardi, N. and Fiorentini, A., (1991), Visual field asymmetries in pattern discrimination: A sign of asymmetry in cortical visual field representation? *Vision Research*, **31**: 1831-1836.

- [2] Biederman, I., (1987), Recognition by components: A theory of human image understanding, *Psychological Review*, **94**: 115–145.
- [3] Braun, J., (1993), Shape-from-shading is independent of visual attention and may be a ‘texton’, *Spatial Vision*, **7**: 311–322.
- [4] Christman, S. D., (1993), Local-global processing in the upper versus lower visual fields, *Bulletin of the Psychonomic Society*, **31**: 275–278.
- [5] Edgar, G. and Smith, A., (1990), Hemifield differences in perceived spatial frequency, *Perception*, **19**: 759–766.
- [6] Efron, R. and Yund, E. W., (1996), Spatial nonuniformities in visual search, *Brain and Cognition*, **31**: 331–368.
- [7] Enroth-Cugell, C. and Robson, J. G., (1966), The contrast sensitivity of retinal ganglion cells of the cat, *Journal of Physiology*, **187**: 517–552.
- [8] Felleman, D. J. and Van Essen, D. C., (1991), Distributed hierarchical processing in the primate visual cortex, *Cerebral Cortex*, **1**: 1–47.
- [9] Howard, I. P., Bergström, S. S., and Ohmi, M., (1990), Shape from shading in different frames of reference, *Perception*, **19**: 523–530.
- [10] Humphrey, G. K., Symons, L. A., Herbert, A. M., and Goodale, M. A., (1996), A neurological dissociation between shape from shading and shape from edges, *Behavioural Brain Research*, **76**: 117–125.
- [11] Kleffner, D. A. and Ramachandran, V. S., (1992), On the perception of shape from shading, *Perception and Psychophysics*, **52**: 18–36.
- [12] Lamb, M. R. and Yund, E. W., (1996), Spatial frequency and attention: Effects of level-, target-, and location-repetition on the processing of global and local forms, *Perception and Psychophysics*, **58**: 363–373.
- [13] Marr, D. and Hildreth, E., (1980), Theory of edge detection, *Proceedings of the Royal Society of London*, **B200**: 269–294.
- [14] Milner, A. D. and Goodale, M. A., (1995), *The visual brain in action*, Oxford: Oxford University Press.
- [15] Murray, I., MacCana, F., and Kulikowski, J., (1983), Contributions of two movement detecting systems to central and peripheral vision, *Vision Research*, **23**: 151–159.
- [16] Navon, D., (1977), Forest before trees: The precedence of global features in visual perception, *Cognitive Psychology*, **9**: 353–383.
- [17] Previc, F. H., (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.
- [18] Previc, F. H., (1996), Attentional and oculomotor influences on visual field anisotropies in visual search performance, *Visual Cognition*, **3**: 277–301.
- [19] Previc, F. H. and Blume, J., (1993), Visual search asymmetries in three-dimensional space, *Vision Research*, **33**: 2697–2704.
- [20] Ramachandran, V. S., (1988), Perceiving shape from shading, *Scientific American*, **269**: 76–83.
- [21] Rayner, K., Slowiczek, M. L., Clifton, C., and Bertera, J. H., (1983), Latency of sequential eye movements: Implications for reading, *Journal of Experimental Psychology: Human Perception and Performance*, **9**: 912–922.
- [22] Rijdsdijk, J., Kroon, J., and van der Wildt, G., (1980), Contrast sensitivity as a function of position on the retina, *Vision Research*, **20**: 235–241.
- [23] Rubin, N., Nakayama, K., and Shapley, R., (1996), Enhanced perception of illusory contours in the lower versus upper visual hemifields, *Science*, **271**: 651–653.
- [24] Ungerleider, L. G. and Mishkin, M., (1982), Two cortical visual systems, In D. J. Ingle, M. A. Goodale, and R. W. J. Mansfield (Eds.), *Analysis of visual behavior*, Cambridge, Mass.: MIT Press.
- [25] Wenderoth, P. and Hickey, N., (1993), Object and head orientation effects on symmetry perception defined by shape from shading, *Perception*, **22**: 1121–1130.
- [26] Yund, E. W., Efron, R., and Nichols, D. R., (1990), Detectability gradients as a function of target location, *Brain and Cognition*, **12**: 1–16.
- [27] Zeki, S., (1969), Representation of the central visual fields in prestriate cortex of monkey, *Brain Research*, **14**: 271–291.