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Perceived length in the central visual field: evidence for visual field asymmetries☆

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Abstract

Visual performance for judging the length of a simultaneously presented pair of radial lines, reciprocally opposed by 180° at a central fixation point, was assessed for 24 radial positions of test lines, for three viewing conditions (binocular, left and right monocular) and five different standard line sizes (1.43–7.13°). Generally, the results showed underestimation of the test line. Furthermore, clear visual field asymmetries were observed between the upper versus lower visual fields and the left versus right visual fields with greater underestimation for test lines presented in the lower and right visual fields. Also, asymmetries tended to be strongest along the 30 and 150° radial orientations. Fourier analysis indicated that these asymmetries are mainly described by summing up the f0, f1, f2 and f5 components. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

There are a number of recent papers proposing that visual processing for a given eccentricity may differ depending on the visual field location (Fahle & Schmid, 1988; Edwards & Badcock, 1993; Rubin, Nakayama & Shapley, 1996; Bilodeau & Faubert, 1997, 1999, in addition, see Previc, 1990 for review). Studies have shown that the perception of illusory contours (Rubin et al.), achromatic motion processing (Edwards & Badcock) and chromatic motion processing (Bilodeau & Faubert, 1997) may be enhanced in the lower visual field as opposed to the upper visual field. It has been suggested that there may be an ecological significance to the functional differences observed between the upper and lower visual fields (Previc).

Furthermore, recent studies have demonstrated that the role of attention for processing visuo-spatial information may differ depending on the visual field location (He, Cavanagh, & Intriligator, 1996; Zackon, Casson, Stelmach, Faubert, & Racette, 1997). He et al. have found attentional resolution to be greater in the lower visual field than the upper visual field for endogenous attentional tasks (focal attention). Because they found no effect of crowding on orientation-specific adaptation, they concluded that the 'attentional filters' must originate from beyond the primary visual cortex. On the other hand, Zackon et al. using an exogenous (transient) technique known as the split priming paradigm (Faubert & von Grünau, 1995), found an enhanced priming effect in the left field of the left eye consistent with the interpretation that both subcortical and cortical priming processes may be involved in such a task. Therefore, there appear to be visual field asymmetries for both bottom-up and top-down processing systems.

Our interest in the present study was two-fold: does the visual system process size differently at various locations of the central visual field?; can we observe upper versus lower and left versus right visual field asymmetries for a simple perceptual judgement task, such as line length?

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2. Methods

2.1. Subjects

Six subjects (two males and four females) with normal or corrected to normal (6/6) monocular and binocular visual acuity participated in this study. The age range was between 18 and 32 years. All subjects gave their informed consent and had a monetary compensation for their participation.

2.2. Apparatus and stimuli

A pair of black radial lines, reciprocally opposed to each other by 180° were presented from the center of the screen (fixation point). Viewing distance was maintained at 50 cm facing a NEC 4FG, 15″ monitor (1024 × 768 pixels) interfaced with a PC486-50 MHz computer equipped with a Diamond SpeedStar24 Video Board. The two radial lines were 0.25 mm thick (1.72 min) on a gray surface (60 cd m^{-2}). The stimuli were beyond the level established as the critical value (one log unit level above threshold) to be contrast independent (Hess & Watt, 1990). The orientation of the lines varied counterclockwise from 0° (horizontal right line) to 345° by 15° steps. On any given trial, one of the lines presented was the standard and the other was the test line. The standard line could subtend a length of 1.43, 2.85, 4.20, 5.71 or 7.13°. The initial size of the test line ranged randomly from 75 to 125% of the simultaneously presented standard.

2.3. Procedure

Before each session, the monitor screen was calibrated to keep the aspect ratio 1:1 and to avoid any distortion of the image. Then, the subject was asked to keep his/her head on a chinrest and the height of the screen center was adjusted to the eye level. Also, the subject was instructed to learn how to keep their gaze at the fixation point as long as they could while adjusting the test line, and trials were allowed for practice until s/he felt confident to start the session. The binocular and left and right monocular conditions were tested in separate sessions and in random order. Each session was run on a different day and the three sessions were finished in a maximum period of a week. Each session took ≈2 h, including short resting periods between trials. The task was to adjust the length of the test line to match the length of the standard by pressing keys on the keyboard while maintaining fixation, which generally took ≈6–9 s to complete. Each line pair was tested five times and in random order. Percent relative errors were calculated with the following formula:

$$\text{Error}\ (\%) = 100*(\text{SS} - \text{TS})/\text{SS}$$

where SS corresponds to the standard size and TS is the adjusted test size.

3. Results

The errors of adjustment of the test line were first submitted to a 3 × 5 × 24 repeated measures ANOVA (three viewing conditions, five standard line sizes and 24 standard line orientations). This analysis indicated that there were significant effect of size ($F(4,20) = 4.46$, $P < 0.01$), orientation ($F(23,115) = 3.51$, $P < 0.001$) and interaction between size and orientation ($F(92,460) = 1.35$, $P < 0.05$). Other effects, such as viewing condition ($F(2,10) = 3.16$, $P > 0.05$), interaction between viewing condition and size ($F(8,40) < 1$), interaction between viewing condition and orientation ($F(46,230) = 1.30$, $P > 0.05$) and interaction among viewing condition, size and orientation ($F(184,920) < 1$) were not significant. Because the effects of viewing condition and its interactions with other factors were not significant, the data were reorganized by averaging them across viewing conditions. Then the means were plotted and interpolated by negative exponentially weighed smoothing curves in polar coordinates as a function of the orientation and the length of the standard line in Fig. 1. The mean errors varied from −7.9 to 0.6% (overall mean of −3.3%) for 1.43° line length, from −4.6 to 2.6% (overall mean of −1.9%) for 2.86° line length, from −5.0 to 1.9% (overall mean of −1.2%) for 4.29° line length, from −5.5 to 1.9% (overall mean of −0.6%) for 5.72° line length and from −3.8 to 3% (overall mean of −0.02%) for 7.13° line length. Therefore, the longer the line, the less it was underestimated.

A Fourier analysis was applied to the data plotted in Fig. 1 to determine the harmonic components of the curves. We used the Mathcad Fourier transform function (CFFT) which is applied in the following way:

$$c := \text{CFFT}(y)$$

The y is the vector containing the input data of length N, where $N = 24$.

The Mathcad's implementation of the fast discrete Fourier transform is based on the Singleton method (Singleton, 1968). The transformation was performed by:

$$c_n = \frac{1}{N} \sum_{k=0}^{N-1} y_k \, e^{-2\pi i k (n/N)}$$

The amplitude and phase of each of the elements of c were computed by:

$$a = |\vec{c}|$$

and

$$\phi = \arg(c)$$

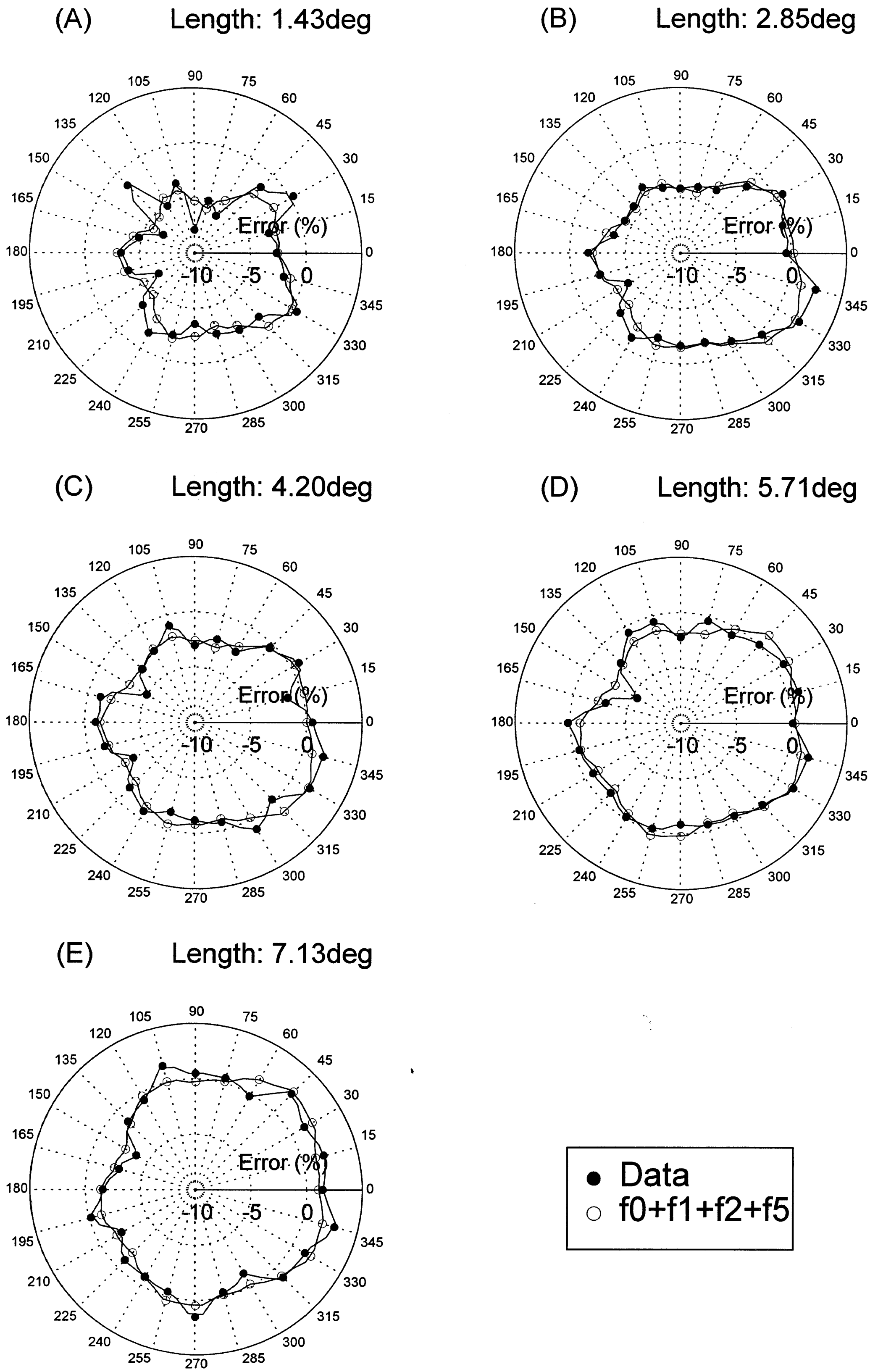

Fig. 1. Curves of the relative error means and their predictions from f0, f1, f2 and f5 Fourier components as a function of the standard line orientation in polar coordinates for line lengths of 1.43° (A), 2.85° (B), 4.20° (C), 5.71° (D) and 7.13° (E). Polar angles are the standard line orientations in degrees and radial axes are relative errors in percents.

A new set of amplitude elements A was defined in the following way:

$$A_r = 2\,a_r$$

$$A_0 = a_0$$

$$A_{(N/2)} = a_{(N/2)}$$

$$\Phi_r = \phi_r$$

where r goes from 0 to $(N/2)$.

This permits the definition of the inverse Fourier transform by this simple expression:

$$y_k = \sum_{r=0}^{N/2} A_r \cdot \cos\left(2\pi \frac{k}{N} \cdot r + \Phi_r\right)$$

The amplitudes and phases of the Fourier components for all line length conditions are shown in Table 1. The f0, f1, f2 and f5 components presented the highest amplitudes on average and they contributed, for the most part, to shape the curves of the original data, as indicated by the curves overlapped in Fig. 1. Fig. 2 demonstrates these Fourier components in isolation for all the line length conditions. In the context of polar coordinates, the f0 corresponds to the 'DC' value generating a perfect circle with no minimum, i.e. the overall mean error of each line length comparisons. The higher components show one, two and five minimums on the polar plots corresponding to the f1, f2 and f5 Fourier components, respectively. Line judgement visual field asymmetries observed in upper versus lower and left versus right visual fields are well represented in the f1 and f2 Fourier plots. The most striking and surprising results come from the f5 component. The f5 component did not only show large amplitudes for all line length conditions, but it was the higher harmonic that demonstrated the least phase variability as demonstrated in Fig. 2 (see also Table 1). Low phase variability for all the testing conditions is indicative that the f5 component represents a reliable characteristic of the data.

To emphasize the effect of the radial orientations on central visual field asymmetry, error of the test line of a given orientation was contrasted to its reciprocal (180° opposed orientation). These error differences were calculated by subtracting the error of the test line at each orientation between 0 and 165° from the error of its reciprocal (between 180 and 345°) for both original and estimated Fourier data (Fig. 3A,B, respectively). The extreme negative and positive values indicate the radial line pair orientations that contributed most to the asymmetries in perceptual line judgements while the values near zero correspond to the line pair orientations that contributed most to symmetrical judgements.

Summarizing the results, the test line was more underestimated at orientations in the lower visual field than in the upper visual field for the shortest line. This asymmetry between the upper and lower visual field tended to decrease with increasing lengths. Furthermore, the test line was less underestimated at orientations in the left visual fields than at orientations in the right visual fields and this asymmetry between the right and left visual fields was independent of line length.

4. Discussion

Our study has determined the ability to judge line size as a function of lengths and orientations throughout the central visual field that had not been previously assessed. We demonstrated that the ability for making line size judgments varies with the size of the standard line and with the orientation of the lines. Furthermore, we demonstrated that the errors in judging size generally corresponds to a perceptual underestimation of the line consistent with previous reports in regard to visually directed judgments for distance (Loomis, DaSilva, Fujita, & Fukusima, 1992). Our data also show that the errors made in such a simple judgement task will be influenced by position and orientation in the central visual field. The errors tend to be greater when the standard line is positioned in the left visual field (test line in the right visual field) compared to when the standard line is positioned in the right visual field (test line in the left). Furthermore, the errors are greater when the standard line is placed in the upper visual field (judgments made in the lower visual fields) than vice versa. These data do not coincide well with the attentional data (He et al., 1996; Zackon et al., 1997) showing that attentional facilitation or priming should produce better judgments in the lower visual field and in the left visual only in the left eye (not for the binocular and right monocular conditions). This would support the notion that our task was perceptual in nature and that, if attention was involved, it was probably involved for processing the test and the standard line equally.

The present study also has implications in the ecological role of the upper and lower visual fields as proposed by Previc (1990). Previc proposed that the upper and lower visual fields may have evolved a functional specialization. For instance, the upper visual field may be specialized for processing distance information, while the lower visual field may have evolved for processing near information. The argument is that visual flow information generated from the immediate surrounding is generated within the lower visual field while locating objects at a distance is generally performed with the upper visual field. This is supported by our data given that the perceptual judgments are best when the test line is in the upper visual field. This difference, however, appears to be present only for the more central visual field (in this case up to 6°) and disappears

Table 1
Amplitudes (A) and phasesin degrees (P) of the Fourier components (fn)

Length:	1.43°		2.85°		4.20°		5.71°		7.13°		Amplitude		Phase (°)	
	A	P	A	P	A	P	A	P	A	P	Mean	S.D.	Mean	S.D.
F0	3.30	180.00	1.90	180.00	1.18	180.00	0.58	180.00	0.02	180.00	1.40	1.27	180.00	0.00
F1	1.79	41.26	2.33	31.99	1.78	31.03	1.50	24.28	1.86	−3.40	1.85	0.30	25.03	17.01
F2	0.63	23.81	1.01	17.55	0.58	26.76	0.49	−55.32	0.32	−114.31	0.61	0.25	−20.30	62.57
F3	0.66	−50.85	0.29	28.30	0.28	100.76	0.66	72.70	0.59	40.90	0.50	0.19	38.36	57.31
F4	0.78	−169.23	0.23	112.13	0.21	−13.41	0.38	−64.30	0.53	−28.41	0.42	0.24	−32.64	101.25
F5	1.16	167.61	0.85	169.54	0.81	179.99	0.90	148.60	0.81	140.98	0.91	0.15	161.34	16.06
F6	0.23	4.76	0.17	68.51	0.72	56.05	0.46	−11.57	0.18	154.95	0.35	0.23	54.54	65.44
F7	1.03	147.16	0.72	156.37	0.49	144.74	0.56	−168.70	0.13	166.88	0.59	0.33	89.29	144.48
F8	0.11	−11.30	0.04	176.73	0.28	107.77	0.23	127.95	0.42	−20.40	0.22	0.15	76.15	87.71
F8	0.11	137.12	0.35	100.74	0.17	82.88	0.16	−153.42	0.30	78.24	0.22	0.10	49.11	115.56
F10	0.60	17.03	0.14	−138.62	0.03	42.22	0.15	36.05	0.24	174.84	0.23	0.22	26.30	111.46
F11	0.97	−47.27	0.05	148.72	0.67	−39.40	0.25	−120.26	0.26	−103.65	0.44	0.37	−32.37	107.09
F12	0.40	180.00	0.04	0.00	0.09	180.00	0.14	180.00	0.36	180.00	0.21	0.16	144.00	80.50

for our furthest eccentricity. It must be pointed out that the task we have used is well suited for distance judgments and therefore must be optimal to solicit the functional specialization advantage for locating and making judgments on objects at a distance attributed to the upper visual field. This is also consistent with the fact that motion defined stimuli appear to be better processed in the lower visual field (Edwards & Badcock, 1993; Bilodeau & Faubert, 1997).

The most puzzling result that transcends from our Fourier analysis of the data was the result of the f5 harmonic, which demonstrated high amplitudes and

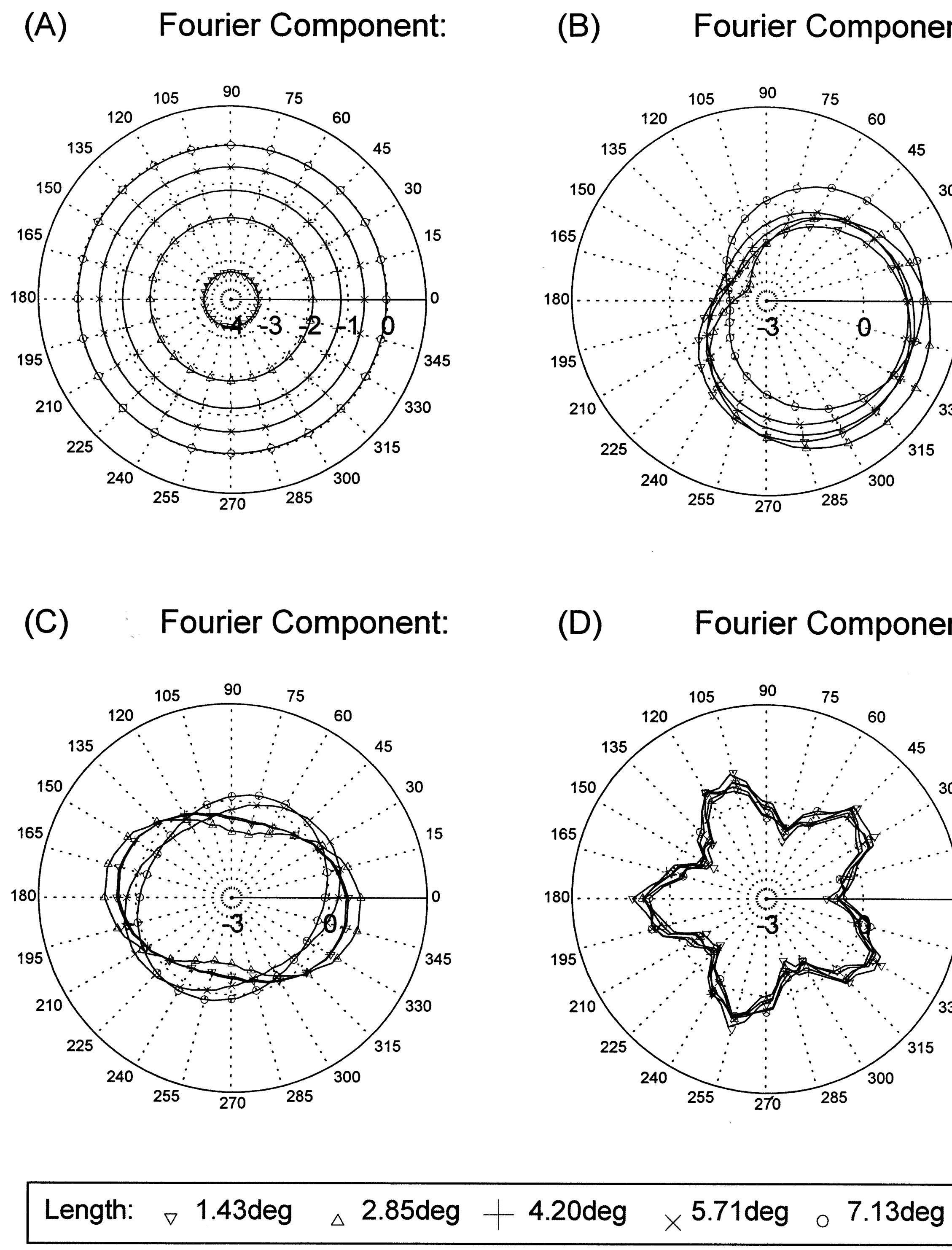

Fig. 2. Curves of f0 (A), f1 (B), f2 (C), and f5 (D) Fourier components as a function of the orientations and lengths of the standard line. Polar angles are the standard line orientations in degrees and radial axes are values of the Fourier components.

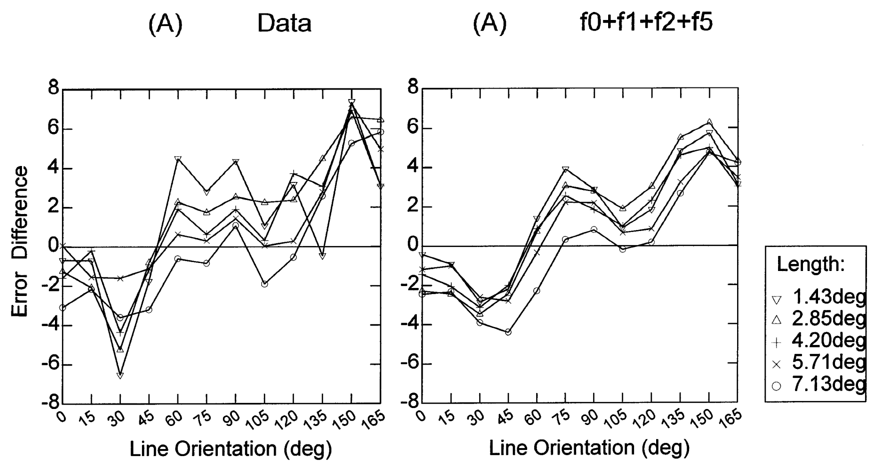

Fig. 3. Error differences between the test line and its reciprocal opposed 180° as a function of the orientations and lengths of the line from original (A) and Fourier components data (B).

low phase variability. These effects cannot represent the classic 'oblique effect' observed in detection and perceptual judgment tasks for achromatic (Apelle, 1972) or chromatic (Bilodeau & Faubert, 1999) spatial stimuli. The oblique effect refers to reduction of sensitivity for stimuli presented at oblique angles. As can be seen in Fig. 2(D), the f5 Fourier component does not follow that rule, where, for instance, there is a large difference between the left and right visual field estimates on the horizontal meridian. It does not represent a systematic error in generating the lines on the computer monitor, given that each length generated was measured with precision to eliminate such artifacts. We must conclude, therefore, that there is a physiological-perceptual component that influences our line length judgments in a systematic way for a variety of line length conditions. What is remarkable is that the phase was almost identical for all the line length conditions. This implies that there is something 'hard-wired' about the perceptual judgment involved in our particular task. In this regard, it is interesting to note the study by Wilkinson, Wilson, and Habak (1998), where they evaluated the capacity to discriminate radial frequency patterns. They found that the efficiency was above 90% for discriminating circles that had five cycles (five bumps on a circle). It appears that we are extremely efficient at discriminating circles that have five discontinuities and that the ability for making such judgments is comparable to hyper-acuity tasks. There may be a link between the underlying processes involved in matching line lengths for diametrically opposed lines in the visual field and making judgments about circle discontinuities.

Although our data has given us information on the capacity to make simple size judgements throughout the visual field, it raises questions in regard to the issue of the role of attention on size judgement tasks. It also raises questions as to whether the visual field asymmetries remain at larger eccentricities. More research is necessary to explore the relation between size judgements and the reduction of the retinal sampling with eccentricity, and to clarify the controversial effect of attention on visual size judgments. A further issue to explore is the role of the visual priming on these size judgements, as there is evidence that focused attention distorts the judgement of visual space (Suzuki & Cavanagh, 1997).

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