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Review Article

Gender Differences in Contrast Thresholds to Biased Stimuli

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Abstract

We present a limited review of the literature on gender differences in visual processing. We then add evidence to that body of literature, reporting the results of an examination of gender differences in response to stimulus conditions favoring magnocellular (MC) and parvocellualr (PC) processing. We measured contrast thresholds and mean reaction times of 24 subjects (15 women, 9 men) to two grating stimuli, one designed to be processed more strongly by MC pathways and the other by PC pathways. There was a significant interaction of gender and stimulus type on contrast thresholds ($F = 4.80$, $p = 0.03$) and reaction times ($F = 4.13$, $p = 0.04$). Women were more sensitive than men to the PC-biased stimulus ($t = 1.94$, $p = 0.05$), but men and women were equally sensitive to the MC-biased stimulus ($t = -1.22$, $p = 0.23$). The results of this experiment add to the body of evidence that women may rely more on parvocellular visual processes than men.

INTRODUCTION

In humans and other primates, physiological and behavioral evidence indicates two anatomically and functionally distinct pathways originating in the magnocellular (MC) and parvocellular (PC) retinal ganglion cells [1,2]. Neurons in the MC pathway are more sensitive to object location, movement, low spatial frequency and global analysis of visual scenes. Neurons in the PC pathway are thought to be more involved with object and pattern recognition as well as color (in particular, red-green) opponency [3,4].

Although previous studies of gender effects on visual processing are heterogeneous, as a group they suggest the possibility of sexual dimorphism in parallel visual processing [5]. For example, Kramer et al. found that, in describing large shapes made up of smaller geometrical elements, boys rely more on the overall shape [6]. Girls, however, are more detailed in their descriptions, referring to the smaller shapes to describe the figures. In free drawings of imagined environmental scenes, boys tend to describe more motion and include more mechanical descriptions while girls tend to use more color [7]. In a study designed to determine the effects of gender and age on dynamic visual acuity, Ishigaki and Miyao found that men tended to detect a small gap at faster drifting rates than do women [8]. The results of these studies suggest that men may rely more on MC processing, while women may rely more on PC processing.

The purpose of this work is two-fold. First, we present a limited review of the literature on gender differences in visual processing. Our second purpose is to add evidence to that body of literature, reporting the results of an experiment that examined gender differences in responses to stimulus conditions favoring MC and PC processing. In our experiment, we measured contrast thresholds and mean reaction times to two grating stimuli, one designed to be processed more strongly by MC pathways and the other by PC pathways. We predicted that women would be more sensitive to the PC-biased stimulus.

MATERIALS AND METHODS

Subjects were eligible if they were between 18 and 45 years old, reported a complete eye examination within the last twelve months, had best-corrected visual acuity of 20/20 or better in each eye, and had normal color vision when tested with psuedoisochromatic plates. The institutional review board of the University of Missouri – St. Louis approved the experimental protocol, and informed consent was obtained from each participant. Twenty-four adults (fifteen women, nine men) participated in the experiment. Three potential participants self-reported a history of corneal refractive surgery and were excluded from participating based on the reported effects of refractive surgery on the contrast sensitivity function [9,10].

Vision Works 4.0 Contrast Sensitivity Software (Vision Research Graphics, Durham, NH) was used to generate and display stimuli on a 21" RGB analog monitor (FlexScanF750i, Eizo Nanao Technologies Inc., Cypress, CA) located 250 cm from the observer. Monocular contrast thresholds were obtained using a QUEST modified staircase algorithm [11]. Contrast thresholds as well as mean reaction times for all positive (yes) responses were analyzed for main effects of gender by repeated-measures analysis of variance (ANOVA). All analyses were performed using SPSS statistical software (SPSS Inc., Chicago, IL).The MC-biased stimulus was a rectangular, one cycle per degree (cpd) achromatic (black and white) grating subtending three (high) by five (wide)

degrees of visual angle. The stimulus also had a surround configuration to limit foveal viewing of the stimulus, and—while the overall stimulus remained stationary—the grating pattern drifted to the left at 30 cycles per second (cps). The PC-biased stimulus was a stationary circular target subtending 1.25 degrees of visual angle. The target was a red on green grating of 20 cpd and did not drift. In addition to the two primary stimuli, four additional stimuli with varied center, full or surround characteristics were randomly interwoven into the stimulus presentation. Some characteristics of these additional stimuli were not as biased toward MC and PC processing. Therefore, only the results from the two primary stimuli are reported here. The onset of each trial was signaled by a short tone, after which a single stimulus was presented. Trials for all six stimuli were interleaved, and participants used a keyboard stroke to indicate whether or not they could detect a grating pattern. Each keystroke was detected and only positive responses were used for reaction time analysis. Contrast thresholds were calculated as the Michelson ratio: $(L_F - L_B)/(L_F + L_B)$, where L_F and L_B represent foreground and background luminance, respectively. For each subject, a single monocular contrast threshold measurement was made for each stimulus using each eye. These monocular measurements were averaged into a single measure for analysis.

RESULTS AND DISCUSSION

Contrast thresholds were positively skewed and were therefore log transformed for analysis. Mean reaction times were normally distributed and represent the mean from all positive (yes) response times for each stimulus. Log transformed contrast thresholds and raw mean reaction times were analyzed for main effects of stimulus type and gender by repeated-measures ANOVA. Simple effects of gender for each stimulus were analyzed using independent t-tests.

Contrast thresholds

For graphical comparisons, contrast thresholds with 95% confidence intervals for each stimulus type are shown in Figure 1. As shown in Table 1, contrast thresholds for the MC-biased stimulus were significantly lower than for the PC-biased stimulus ($F = 246$, $p < 0.001$). This result is consistent with many previous findings of increased contrast gain from magnocellular pathways (e.g., Purpura et al. [12]). The main effect of gender was not significant ($F = 2.43$, $p = 0.12$), but there was a significant interaction of gender and stimulus type (PC-biased vs. MC-biased) on contrast thresholds ($F = 4.80$, $p = 0.03$). As shown in Figure 1, women were more sensitive than men to the PC-biased stimulus ($t = 1.94$, $p = 0.05$), but men and women were equally sensitive to the MC-biased stimulus ($t = -1.22$, $p = 0.23$).

Mean reaction times

Similar effects of gender and stimulus type were found for reaction times, as shown in Table 1 and Figure 2. Both men and women had significantly lower mean reaction times for the MC-biased stimulus than for the PC-biased stimulus ($F = 93.0$, $p < 0.001$). This result is consistent with those of previous studies indicating decreased reaction times to larger and more luminous stimuli [13,14]. There was no main effect of gender ($F = 0.50$, $p = 0.48$), but there was a significant interaction of gender and stimulus type on reaction times ($F = 4.13$, $p = 0.04$). Unlike the results for contrast thresholds, there was no gender difference in reaction times for either the MC or PC-biased stimulus.

In this experiment, we found that women were more sensitive than men to the contrast changes in the small, red-green, stationary stimulus, which is more likely to be processed strongly by the PC pathway. This result is in agreement with previous studies indicating that women may rely more on PC

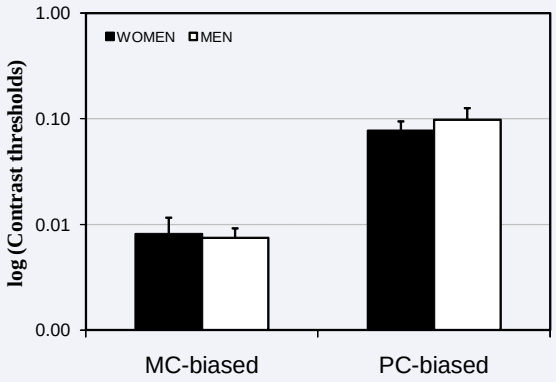

Figure 1 Mean values of contrast thresholds (with 95% CI). Women were more sensitive to the PC-biased stimulus ($p \leq 0.05$; see Table 1).

Table 1: Effect of stimulus type and gender on contrast thresholds and mean reaction times.

	Contrast Thresholds		Mean Reaction Times	
Main Effect	F	p	F	p
Stimulus Type	*246	< 0.001	*93.0	< 0.001
Gender	2.43	0.12	0.50	0.48
Stimulus x Gender	*4.80	0.03	*4.13	0.04
Gender Effect [a]	t	p	t	p
MC-biased	-1.22	0.23	-1.16	0.25
PC-biased	*1.94	0.05	1.66	0.10

[a]Gender effect = independent t-test of [values for men - values for women]
* $p \leq 0.05$

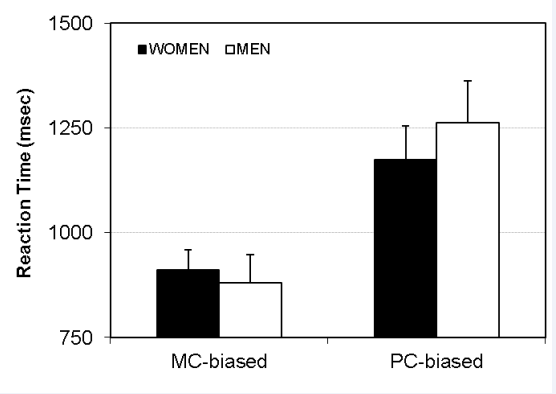

Figure 2 Mean values of mean reaction times (with 95% CI). There was a significant interaction of gender and stimulus type on reaction times ($F = 4.13$, $p = 0.04$). There was no gender difference in reaction times for either the MC or PC-biased stimulus.

processing than males [6,15]. Men had lower contrast thresholds than women to the large, achromatic, drifting stimulus, but the difference was not statistically significant for this target. While previous studies [6-8] indicate a male advantage in some MC processes, the results of studies measuring gender differences in contrast thresholds across spatial frequencies are equivocal [16,17]. Therefore, the lack of a significant finding for the MC-biased stimulus is not unexpected. While neither stimulus is absolutely processed by one parallel pathway or the other, it is reasonable to assume that PC processes underlie sensitivity to the small, red-green target. Likewise, processing for the large, drifting stimulus is certainly biased toward the MC pathways.

Mean reaction times were also used as a measure of visual performance as in at least one previous study [18]. The interaction effect of stimulus type and gender on mean reaction times was significant, but there were no significant gender differences in mean reaction times for either the MC- or PC-biased stimulus. Overall, the results of this experiment add to the body of evidence indicating that there are gender differences in parallel visual processing.

Possible mechanisms for gender differences

Approximately fifteen percent of human females are carriers of sex-linked color deficiencies [19]. In theory, these individuals should have normal color vision since the normal color gene on one of their X chromosomes is dominant and produces a normal phenotype. However, heterozygous carriers often exhibit mild color vision deficiencies on clinical testing. Lyon hypothesized that heterozygous carriers are actually hemizygous in some cells due to X-inactivation during early development of the female embryo [20]. That is, one gene (normal or abnormal) is active at any given point during embryonic development of certain tissues. In the eye, this results in a mosaic of normal and abnormal retina. At least one study [21] has suggested that heterozygous carriers have essentially normal trichromatic vision, while others have found reduced luminous efficiency to long wavelength [22,23]. It is possible, then, that the results of this study indicating gender differences in sensitivity to red-green stimuli were influenced by the inclusion of undetected heterozygous carriers in our study population. However, if some of our female subjects are indeed heterozygous carriers for red-green deficiency, evidence indicates that the advantage in red-green contrast sensitivity might belong to men due to deficient red-green discrimination found in heterozygous carriers [24-26]. It is then unlikely that inclusion of heterozygous carriers for color deficiencies would have produced an overall advantage for the women in our study. Estrogen is a steroid hormone that has significant effects on both male and female reproductive systems. Estrogens also regulate tissue functions outside of the reproductive system. Estrogen receptor (ER) proteins mediate estrogen effects, and at least one type, ER_{β}, has been observed in both male and female ocular structures, including the iris, lacrimal gland, and choroid [27]. ER_{β} proteins have also been found in the retinas of premenopausal women, but not in men or in postmenopausal women. These findings suggest the possibility of direct estrogenic influences on visual processing in the premenopausal women who served as subjects in this study.

It is also possible that estrogens act through an intermediate mechanism.Estrogens influence dopamine release by augmenting glutamate and inhibiting gamma amino butyric acid (GABA) syntheses [28]. It is generally accepted that GABA-mediated cortical inhibition is important in determining visual responses [29], and there is research attributing some differences in visual processing abilities to sex hormone levels [30-32]. A review by Parlee [33] highlighted evidence for cyclical effects on visual processing, and a later review [34] of this research suggests there is an increased cortical capacity for visual information processing in women during peak estradiol levels of the menstrual cycle.

Only a few studies have investigated the effects of the menstrual cycle on color vision. Finkelstein [35] suggested an increase in the wavelength position of unique green (toward yellow) as well as restricted color visual fields during the low estrogen menstrual phase. Lorenzetti [36] also found constricted red and green color fields with decreased yellow and green sensitivity during the menstrual phase. While others [37,38] have not been able to demonstrate repeatable changes in standard achromatic visual fields across the menstrual cycle, at least one study [39] has suggested decreased sensitivity to short-wavelength stimuli during the relatively low estradiol luteal phase. In a study of cyclical effects on isolated S-, M- and L-cone mechanisms, Eisner et al. [40] found cyclical effects on S-cone mechanisms, but the cyclical effects were more limited for M- and L-cone mechanisms.

In addition to estrogen, progesterone is implicated in visual processing. Progesterone is thought to antagonize estrogens by increasing CNS sensitivity to GABA and decreasing the CNS response to glutamate [41]. It is then possible that cycling estrogen and progesterone or their interaction enhance PC-processing in women.

CONCLUSIONS

The results reported here add to the body of evidence that women may rely more on PC visual processing than do men. However, PC processing produces a bias for both color-opponency (particularly red-green) and fine, spatial details. Unfortunately, our experiment did not separate these aspects, and further investigation is warranted into whether the female advantage is based on chromatic or spatial aspects of visual processing or perhaps a combination. In addition, it would be of interest to determine whether the effects reported here are cyclical, relying on hormonal changes measured across the menstrual cycle.

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