Brief Report

Lightness Peaks during the Menstrual Phase: A Retrospective Challenge to a Visual Arousal Theory of Estrogen

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Lightness Peaks during the Menstrual Phase: A Retrospective Challenge to a Visual Arousal Theory of Estrogen

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Abstract: 1) Background: The influence of estrogen on cognitive and perceptual functions is debated. Some research suggests that estrogen increases arousal, improving cognitive function, while others propose that increased arousal might reduce performance on certain tasks. This study investigates the effects of menstrual cycle phase and estrogen levels on lightness perception in cycling women and hormonal contraceptive (HC) users. (2) Methods: Estrogen levels were determined from saliva samples collected at three sessions aligned with different menstrual phases in 16 women (9 with natural cycles, 7 HC users). The effects of wavelength and menstrual cycle phase on lightness perception were analyzed, followed by post-hoc comparisons and correlations between lightness perception and estrogen levels for both cycling women and HC users. (3) Results: Lightness varied by menstrual phase (MCP) in cycling women and was slightly higher during the low estrogen menstrual phase compared to peri-ovulation or luteal phases. In HC users, lightness measures were equivalent across phases. For cycling women, lightness was negatively correlated with estrogen for the green and green-yellow stimuli. There were no such associations among HC users. (4) Conclusions: This report challenges the concept that high estrogen phases of the menstrual cycle always positively influence perception. Conversely, the present results revealed that—at least in cycling, non-hormonal contraceptive users—lightness perception was both at a maximum during the low estrogen menstrual phase and negatively associated with estrogen levels across all tested wavelengths.

Keywords: lightness; heterochromatic flicker photometry; menstrual cycle; estrogen

1. Introduction

Estrogen is a steroid sex hormone that is primarily associated with female reproductive functioning. However, it also plays a role in various physiological processes, including brain function [1]. While there is significant variation between individuals [2], it is well-established that estrogen levels fluctuate during the menstrual cycle. Estrogen is typically at a minimum during the first week of the cycle (i.e., menstrual phase) and peaks around day 12 or 13 (i.e., pre-ovulation). Levels quickly fall off after ovulation but gradually increase to a smaller peak at approximately the midpoint of the luteal phase (~ day 22). Investigators can then use menstrual cycle phase as a surrogate for hormone levels when accounting for behavioral or perceptual changes in women [2]. However, great care should be taken to account for individual differences, unless hormones are directly measured. Even if precisely measured, the directional influence of hormonal changes on perception is debated. Some research has shown that estrogen increases cognitive arousal and suggests decreased cognitive or perceptual function during low estrogen (i.e., menstrual) phases of the cycle [3,4]. Kopell et al. further argued in favor of a "general arousal theory" whereby females' increased sensitivity to visual cues from males during high estrogen ovulation increases the chance of mating during peak fertility [3]. While it is well-established that sex differences are not equivalent to or even derived from changes across the menstrual cycle [5], an arousal theory is supported by evidence that male-female differences in color descriptions may come as much from increased attention in females (i.e., relative male 'carelessness') as it does psychological or physiological structures [6]. Other studies, however, have suggested that increased arousal may decrease performance on certain tasks [e.g., 7]. These

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alternate positions are based on the idea that increased sensitivity to light during higher arousal phases of the menstrual cycle (i.e., near ovulation) may cause retinal cells to become saturated with light [8]. The overall saturated retina results in increased difference thresholds and decreased sensitivity [7].

There is a rich historical, though equivocal, body of evidence suggesting that changes across the menstrual cycle affect visual sensitivity [see 9,10 for reviews]. Experimental paradigms have varied significantly, and much of this research predates the first detection of estrogen receptors in the mammalian and human retinas [11,12]. However, as far back as the late 19th and early 20th centuries, researchers found restricted color visual fields during the menstrual phase with specific changes in the middle (green and yellow) portions of the visual spectrum [13,14]. More recent evidence suggests little effect of menstrual cycle phase on achromatic (i.e., white on black) automated visual fields but decreased sensitivity to short-wavelength (i.e., blue) stimuli during the luteal phase [15,16]. Eisner et al. concluded that hormonal activation effects could alter retinal function across the short time span of a typical menstrual cycle [17]. They found increases and decreases in sensitivity near ovulation and pre-menstrually, respectively, that were most pronounced for short wavelength (blue) stimuli but also present in some subjects for middle wavelength (green) and long wavelength (red) sensitive mechanisms. At least one other study found greater color discrimination near ovulation than during menstrual or luteal phases, but they did not attempt to differentiate between psychological and hormonal roles [18]. Conversely, at least one study found faster color judgments during the menstrual phase when compared to peri-ovulation, particularly for non-cognitive blue and yellow stimuli [19].

Studies involving the influence of estrogen surrogates or modulators on color visibility have also produced equivocal results. For example, tamoxifen (a common treatment in breast cancer) primarily acts as a selective estrogen receptor modulator [SERM] by inhibiting the growth of estrogen-responsive breast cancer cells. However, tamoxifen can have various side effects, including those related to vision. Eisner & Incognito investigated these changes in short- and long-term tamoxifen users and found that tamoxifen use decreased the visibility of short-wavelength light [20]. Eisner et al. also demonstrated that long-term tamoxifen use decreased sensitivity during short wavelength (i.e., blue on yellow) automated perimetry [21].

The overall equivocal nature of these findings necessitates direct measurement of estrogen in lieu of categorical assumptions about hormone levels. A recent investigation by the present author involving chromatic brightness differences only produced negative menstrual cycle findings [22; see 23 for preprint]. That report did, however, reveal that models of brightness (i.e., the apparent intensity of light) were associated with lightness (i.e., the apparent intensity of light relative to an area illuminated by white light) changes as well as changes in estrogen for normally cycling women but—to a lesser extent—hormonal contraceptive users [22]. However, while estrogen and menstrual cycle phase were both shown to affect the ratio of perceived brightness to perceived lightness (i.e., the Helmholtz-Kohlrausch), the effects of the menstrual cycle on *lightness* alone were never reported. The present work addresses this omission and uses the previously collected data [see https://doi.org/10.6084/m9.figshare.23786796] to support this brief report on the effects of both menstrual cycle phase (MCP) and estrogen (EST) levels on lightness perception in both normally cycling women and hormonal contraceptive users.

2. Materials and Methods

The methods are fully reported in an investigation of the Helmholtz-Kohlrausch effect [22]. In brief, 16 women (nine normally cycling, seven hormonal contraceptive users) participated in three sessions coinciding with the menstrual (days 1-7), peri-ovulation (~day 12), and luteal (~day 21-22) phases of their menstrual cycle. All subjects collected saliva at home the day of each session, and all samples were mailed for analysis the day they were received. Both naturally occurring (i.e., endogenous) and synthetic estrogen were analyzed by double antibody radioimmunoassay (RIA) within 21 days.

Subjects were not fully dark adapted; rather, they were adapted to a low background luminance of 0.4 cd/m^2 for 30 minutes prior to each session. After which, heterochromatic flicker matches (HFM)

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were used to measure lightness across five wavelengths (or colors)—450 (blue), 520 (green), 560 (green-yellow), 580 (yellow), and 650 nm (red). The test (or color) channel was produced by a narrow bandpass interference filter (NBIF) wheel producing each of the five test wavelengths. The reference channel was a spectrally broad (i.e., white) 5 cd/m^2 circular stimulus that flickered against the test channel at 18 cycles/sec (Hz). The viewing stimulus subtended 2.5° at a viewing distance of 43 cm. Subjects were asked to adjust the intensity of the test light (while the white light luminance was held constant at 5 cd/m^2) until they perceived a steady, non-flickering light. This was repeated four times for each of the five wavelengths at each session. The luminance values for the four trials for each wavelength were averaged, and the relative luminosity (RL or *lightness*) was derived by dividing the reference stimulus luminance (5 cd/m^2) by this average. By example, if an observer required 50 cd/m^2 on average at 450 nm to match the 5 cd/m^2 white stimulus, the RL at 450 nm is 5 cd-m^{-2}/50 cd-m^{-2} or 0.10 at 450 nm. Overall, the *lighter* the test color, the less luminance required to match the white stimulus. RL functions by HFM typically peak around 560 nm and are at minimum near the low and high ends of the visual spectrum [24].

In the present investigation, repeated measures analysis of variance (RM ANOVA) was used to determine the within-subjects effects of wavelength and MCP on lightness (RL) for both normally cycling women and hormonal contraceptive (HC) users. Post-hoc comparisons were used to determine pairwise differences in RL between menstrual, peri-ovulation, and luteal phases and—where appropriate—for each wavelength. Lastly, correlations were calculated between RL and estrogen levels at each wavelength. This was done separately for cycling women and HC users.

3. Results

3.1. Effects of menstrual cycle phase (MCP) on relative luminosity (RL)

Mean RL measures across wavelength by MCP are shown separately for cycling women and HC users in Figure 1. For cycling women (see Figure 1[a]), RL measures varied across wavelength (F[4,20] = 163, $p < 0.001$, $\eta^2 = 0.970$) and by MCP (F[2,10] = 4.98, $p = 0.032$, $\eta^2 = 0.499$). RL measures were slightly higher in cycling women during the menstrual phase, but the paired comparisons (i.e., mean differences [MD]) did not reach statistical significance (MD [menstrual – ovulation] = 0.110, $p = 0.080$; MD [menstrual – luteal] = 0.122, $p = 0.071$). In HC users (see Figure 1[b]), RL measures varied across wavelength (F[4,20] = 428, $p < 0.001$, $\eta^2 = 0.988$) but were equivalent by MCP (F[2,10] = 0.165, $p = 0.850$).

3.2. Relationships between relative luminosity (RL) and estrogen (EST) levels

Linear relationships between RL measures and EST are shown separately for cycling women and HC users in Figure 2. For cycling women (see Figure 2[a]), RL measures were negatively correlated with EST for all wavelengths, and significantly so for the green (520 nm; r = -0.494, p = 0.006) and green-yellow (560 nm; r = -0.552, p = 0.006) stimuli. There were strong trends for the blue (450 nm), yellow (580 nm), and red (650 nm) stimuli. For HC users (see Figure 2[b]), there was little relationship between RL measures and EST levels across all wavelengths.

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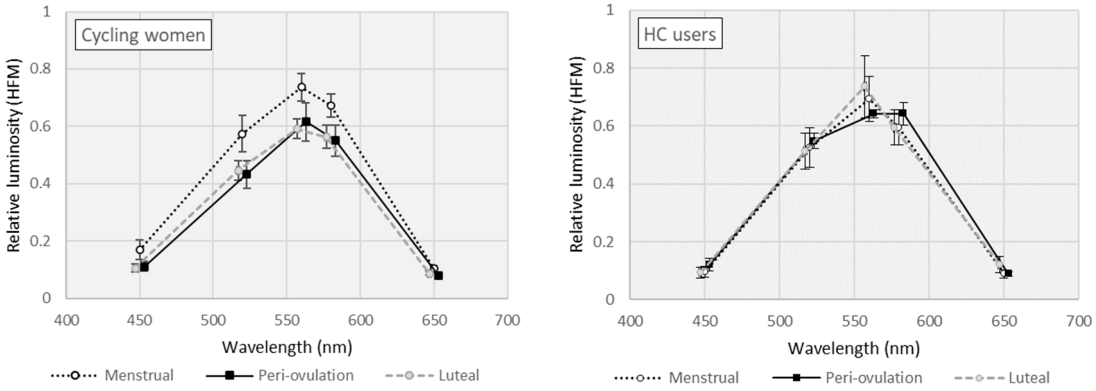
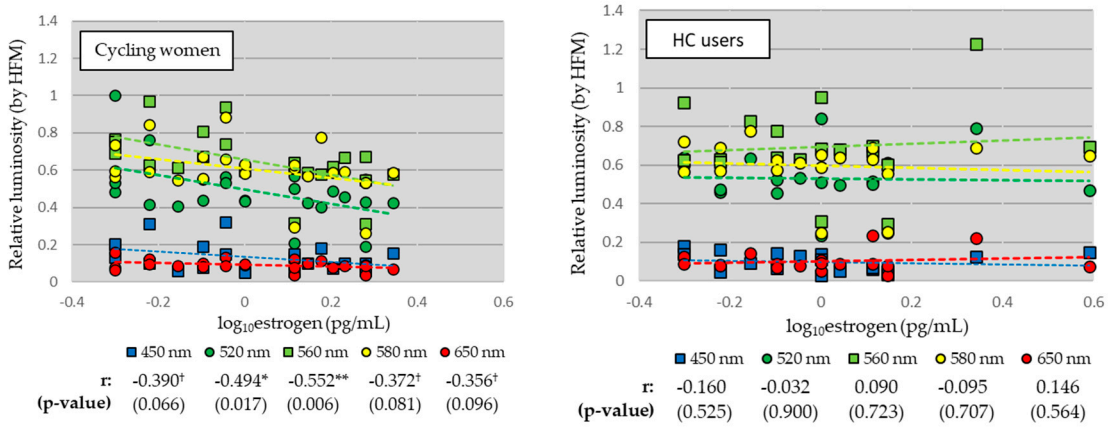


(**a**) (**b**)

Figure 1. Relative luminosity (RL) curves for (**a**) cycling women; (**b**) hormonal contraceptive (HC) users. (Error bars represent ± 1 SE).



(**a**) (**b**)

Figure 2. Linear relationships between relative luminosity (RL) and estrogen levels (**a**) cycling women; (**b**) hormonal contraceptive (HC) users. Correlation coefficients (Pearson's r) and significance (p-value) reported. **p < 0.01, *p < 0.05, †p < 0.10.

4. Discussion

The current study investigated the relationship between estrogen levels and lightness perception separately by hormonal contraceptive (HC) use across different menstrual cycle phases. The results revealed several important findings and implications.

Analysis across wavelengths for cycling women and HC users added little to the discussion, as RL measures varied significantly across wavelengths in both cycling women and HC users. However, the effect of menstrual cycle phase on RL measures was only statistically significant in cycling women (and not HC users), predicting almost 50% of the variance in lightness. RL measures were slightly elevated in cycling women during the menstrual phase across all wavelengths. While the observed mean differences did not reach statistical significance on pairwise comparisons between menstrual and luteal or peri-ovulatory phases, these findings imply a perceptual advantage during menstruation. This result is a challenge to previous implications that high hormone phases of the menstrual cycle (i.e., peri-ovulation) produce perceptual advantages [3]. There have been previous challenges to the theory of perceptual disadvantages during low estrogen menstrual phases. For example, Cockrell et al. failed to find decreased perceptual task performance during menstruation, in spite of impaired mood and cognitive functioning [25]. At least one review has concluded against any menstrual cycle effect on perceptual or psychophysical measures [26], but there are even a few

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previous results that compare with the present finding of a perceptual advantage during menstruation [7,19].

The investigation into the relationships between RL and estrogen levels revealed intriguing patterns. In cycling women, a negative correlation was observed between RL measures and estrogen levels for several wavelengths. Notably, significant correlations were found for the green (520 nm; r = -0.494) and green-yellow (560 nm; r = -0.552) stimuli, with strong trends apparent for the blue (450 nm), yellow (580 nm), and red (650 nm) stimuli. These findings suggesting decreased lightness perception with increased estrogen levels provide the strongest challenge to a perceptual "arousal hypothesis" of estrogen. One explanation for the present perceptual advantage during low estrogen phases is that human retinas become more saturated for broadband (i.e., white) than narrowband (i.e., color) stimuli during excited (i.e., high estrogen) phases [7]. Therefore, the present measure of lightness (i.e., sensitivity to color/sensitivity to white) would be lower during low estrogen phases.

Perhaps the most interesting present finding is the lack of menstrual cycle influence on lightness in HC users. RL measures were essentially equivalent between phases. HC users also exhibited weak relationships between RL measures and estrogen levels across all wavelengths. This discrepancy in the relationship between RL and estrogen for cycling women versus HC users could further be attributed to the hormonal modulation introduced by contraceptive use, which may decouple the typical hormonal fluctuations observed in natural menstrual cycles. While the mechanisms varied significantly from the present study, multiple previous results suggest a similar perceptual dimorphism between cycling women and HC users [22,27].

Overall, the observed negative correlations between lightness and estrogen levels in cycling women raise intriguing questions about the underlying mechanisms linking estrogen and lightness perception. The present study provides evidence that variations in estrogen levels might indeed negatively influence the perception of lightness, particularly at specific wavelengths.

It is important to acknowledge the limitations of this report, such as the relatively small sample size. Additionally, the present report is a retrospective, unplanned analysis of estrogen's effects on lightness. Future research with larger and more diverse samples, along with a more refined experimental design, could provide a deeper understanding of the relationship between estrogen and lightness perception. Further investigations could examine the neural pathways and mechanisms through which estrogen influences sensory perception, shedding light on the observed correlations.

5. Conclusion

In conclusion, the current study highlights in naturally cycling women the complex interplay between lightness perception and estrogen levels across different menstrual cycle phases. The results surprisingly suggest a negative association between estrogen and lightness perception, contributing to the growing body of literature exploring the effects of estrogen and other sex hormones on sensory perception and cognitive processes.

Supplemental information: RL measures were positively skewed (other than at 580 nm), and all were positively (i.e., lepto-) kurtotic. However, logarithmic transformations resulted in negatively skewed RL measures that were still significantly leptokurtotic. Therefore, raw RL measures were used for analysis. Raw EST levels were also positively skewed and leptokurtotic, but log-transformed EST levels were normally distributed (via one-sample Kolmogorov-Smirnov test; p = 0.200) and used for analysis.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the University of Missouri – St Louis (#2006-05-06).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are openly available in FigShare at doi: 10.6084/m9.figshare.23786796.

Conflicts of Interest: The author declares that—while overall brightness data were reported elsewhere [22]—the present reports of relative luminosity and its relationship with menstrual cycle phase and estrogen levels have not been previously reported.

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