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# Facial coloration tracks changes in women's estradiol

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**Summary** Red facial coloration is an important social cue in many primate species, including humans. In such species, the vasodilatory effects of estradiol may cause red facial coloration to change systematically during females' ovarian cycle. Although increased red facial coloration during estrus has been observed in female mandrills (*Mandrillus sphinx*) and rhesus macaques (*Macaca mulatta*), evidence linking primate facial color changes directly to changes in measured estradiol is lacking. Addressing this issue, we used a longitudinal design to demonstrate that red facial coloration tracks within-subject changes in women's estradiol, but not within-subject changes in women's progesterone or estradiol-to-progesterone ratio. Moreover, the relationship between estradiol and facial redness was observed in two independent samples of women ($N = 50$ and $N = 65$). Our results suggest that changes in facial coloration may provide cues of women's fertility and present the first evidence for a direct link between estradiol and female facial redness in a primate species.


## 1. Introduction

Facial coloration appears to function as an important social cue in many non-human primate species (Setchell and Dixson, 2001; Waitt et al., 2003; Setchell et al., 2006; Dubuc et al., 2009; Higham et al., 2010). For example, facial redness is associated with status in male mandrills (*Mandrillus sphinx*, Setchell and Dixson, 2001) and attractiveness in male rhesus macaques (*Macaca mulatta*, Waitt et al., 2003). In some species of non-human primate, facial coloration may also function as a fertility cue (Setchell et al., 2006; Dubuc et al., 2009; Higham et al., 2010). For example, female rhesus macaques' (Dubuc et al., 2009) and mandrills' (Setchell et al., 2006) facial skin becomes redder during the fertile phase of their ovarian cycles, complementing findings for similar changes in the color of female hindquarter skin (Dixson, 1998). Female rhesus macaques' facial skin may

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also become darker during the fertile phase of their ovarian cycles (Higham et al., 2010).

The majority of research examining these changes in facial coloration has focused on investigating the ultimate functions of these color changes (Setchell et al., 2006; Dubuc et al., 2009; Higham et al., 2010, 2011). Consequently, research into the proximate mechanisms through which these changes in facial coloration might occur has been neglected. It has been assumed that the vasodilatory effects of estradiol (Sobrino et al., 2009) drive these changes in facial coloration (Dixson, 1998; Dubuc et al., 2009), as well as the analogous changes in the color of female hindquarter skin (Dixson, 1998; Dubuc et al., 2009). Estradiol may increase blood flow to blood vessels close to the surface of the skin, increasing skin redness (Dixson, 1998; Dubuc et al., 2009). While this potential mechanism for changes in female skin color has been widely accepted, there is no direct evidence that changes in female skin color closely track within-subject changes in estradiol (Dubuc et al., 2009). Consequently, a critical assumption of the assumed proximate mechanism for changes in primate skin coloration during the ovarian cycle remains untested.

Recent work suggests that facial skin coloration may also function as an important social cue in humans. For example, increasing red, yellow, and light skin coloration increases the perceived health of white European and black African women's faces (Stephen et al., 2009a, 2009b; Re et al., 2011). Increasing red and yellow facial skin coloration also increases women's attractiveness (Re et al., 2011; Whitehead et al., 2012a, 2012b). These effects are thought to primarily reflect responses to facial cues of cardiovascular health (Stephen et al., 2009a) and good diet (Stephen et al., 2011; Whitehead et al., 2012b). However, other research suggests that facial skin coloration may be a viable cue to women's current fertility status. For example, one recent study reported that women's facial skin was redder on the day of ovulation, when fertility and estradiol are both high, than it was at the end of the luteal phase, when fertility and estradiol are both low (Oberzaucher et al., 2012). However, the relationship between estradiol and fertility is not linear; estradiol can also be relatively high in the mid-luteal phase, when fertility is low (Alliende, 2002). Accordingly, another study comparing women's facial skin coloration between the high-fertility, high-estradiol ovulatory phase and the low-fertility, high-estradiol mid-luteal phase found no differences in coloration between these points of the cycle (Samson et al., 2011). If women's facial skin coloration does change systematically during the menstrual cycle, it is plausible that the vasodilatory effects of estradiol drive these color changes. However, like research on color changes in other primates, it has not yet been established that changes in women's facial skin coloration do, in fact, track changes in estradiol.

In light of the above, we used a longitudinal design to investigate the relationships between changes in objective measures of women's facial coloration and changes in their salivary estradiol, progesterone, and estradiol-to-progesterone ratio during the menstrual cycle. We investigated these relationships in two independent samples of women in which each woman was tested in five weekly test sessions. Following other recent studies of women's facial coloration (Stephen et al., 2009b, 2011; Samson et al., 2011; Whitehead et al., 2012a), we measured facial coloration on the red (a*), yellow (b*), and light (L*) axes in CIELab color space (Commission Internationale de L'Éclairage, 1976). Note that our study design focuses on the relationship between measured hormone levels and facial coloration. This approach has been used in several recent studies of women's responses to facial cues (Pisanski et al., 2014; Wang et al., 2014; Hahn et al., 2015) and allows for a more direct test of associations between hormone levels and aspects of facial coloration than a simple comparison of color measures obtained during different phases of the menstrual cycle would allow.

## 2. Methods

### 2.1. Participants

All participants were students at the University of Glasgow and each completed five weekly test sessions. Participants were recruited only if they were not currently using any hormonal supplements (e.g., oral contraceptives), had not used any form of hormonal supplements in the 90 days prior to their participation, and had never used sunbeds or tanning products. None of the participants reported being pregnant, having been pregnant recently, or breastfeeding. We tested two independent samples of women. Sample 1 consisted of 50 white women (mean age = 20.9 years, SD = 2.38 years). Sample 2 consisted of 66 white women (mean age = 21.5 years, SD = 2.95 years). No woman appeared in both samples. All women provided written informed consent to participate.

### 2.2. Color measures

In each of the five test sessions, each participant first cleaned her face with hypoallergenic face wipes to remove any make up. A full-face digital photograph was taken a minimum of 10 min later. Photographs were taken in a small windowless room against a constant background, under standardized diffuse lighting conditions, and participants were instructed to pose with a neutral expression. Camera-to-head distance and camera settings were held constant. Since women may be more likely to wear red or pink clothing during the fertile phase of their menstrual cycle (Beall and Tracy, 2013) and these changes in clothing could influence measures of facial coloration due to reflectance, participants wore a white smock covering their clothing when photographed. Photographs were taken using a Nikon D300S digital camera and a GretagMacbeth 24-square ColorChecker chart was included in each image for use in color calibration.

Next, face images were color calibrated using a least-squares transform from an 11-expression polynomial expansion developed to standardize color information across images (Hong et al., 2001). Skin patches (150 × 150 pixels) were then extracted from the same fixed location (relative to the pupil) on the left and right cheeks of each woman's five face images. The average red (a*), yellow (b*), and light (L*) values for each patch were then measured in CIELab color space (Commission Internationale de L'Éclairage, 1976). Color measures obtained from images in this way produce similar results to spectrophotometry