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Coloration in different areas of facial skin is a cue to health: The role of cheek redness and periorbital luminance in health perception

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ABSTRACT

Looking healthy is a desirable trait, and facial skin color is a predictor of perceived health. However, skin conditions that cause dissatisfaction with appearance are specific to particular facial areas. We investigated whether color variation in facial skin is related to perceived health. Study 1 defined three areas based on color differences between faces perceived as healthy or unhealthy: the forehead, periorbital areas, and the cheeks. Periorbital luminance and cheek redness predicted perceived health, as did global skin yellowness. In Study 2, increased luminance and redness caused faces to be perceived as healthier, but only when the increase was in the periorbital and cheek areas, respectively. Manipulating each area separately in Study 3 revealed cheek redness and periorbital luminance equally increased perceived health, with low periorbital luminance more negatively affecting perceptions. These findings show that color variation in facial skin is a cue for health perception in female faces.

Introduction

The idea that our faces reflect our health is a notion that dates back centuries (Bridges, 2012), and having a healthy appearance is universally desired. Appearing healthy contributes to a number of factors that influence attractiveness (Rhodes et al., 2007), which in turn strongly affects self-esteem (Feingold, 1992), and individuals who appear healthy are more likely to be selected as leaders across different scenarios, even compared to those who appear intelligent (Spisak, Blaker, Lefevre, Moore, & Krebbers, 2014). Clearly, a healthy appearance is a trait with important social outcomes, as well personal outcomes relating to body image. But what makes a face appear healthy? Here, we describe work investigating whether variation in skin color between different parts of the face is a cue for perceiving health.

Though attributes of facial shape, such as facial adiposity, are cues to health (Coetzee, Perrett, & Stephen, 2009; Coetzee, Re, Perrett, Tiddeman, & Xiao, 2011), most research on facial health perception has focused on skin properties. Indeed, observers can accurately identify composite faces made of individuals with high or low self-reported health, even when shape cues are removed; skin property cues are all that are required for accurate identification of health (Jones, Kramer, & Ward, 2012). One skin property that is important for health perception is the evenness, or homogeneity, of the skin tone. With shape invariant faces, an even skin color distribution (e.g., an absence of dark spots or blemishes) predicts perceived health (Fink, Grammer, & Matts, 2006), and smoothing color distribution increases perceived health in natural faces (Samson, Fink, & Matts, 2011). An even color distribution visible in small snapshots of skin is able to predict global ratings of facial health (Matts, Fink, Grammer, & Burquest, 2007), as well as attractiveness (Jones, Little, Burt, & Perrett, 2004).

At a more holistic level, the overall color of the skin is another important cue to perceived health. Observers perceive faces with lighter, redder, and yellow skin as healthier looking (Stephen, Law Smith, Stirrat, & Perrett, 2009). These colorations are linked to biological traits relevant to health. For example, observers judge faces with higher levels of redness healthier, if that redness comes from oxygenated blood (Stephen, Coetzee, Law Smith, & Perrett, 2009). Lower levels of this coloration suggest reduced blood flow to the

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skin, which is associated with respiratory or cardiovascular illness (Ponsonby, Dwyer, & Couper, 1997). Facial redness may, therefore, act as a cue to the cardiovascular health of an individual. Recent research has highlighted the importance of skin color in perceiving health by examining its interaction with shape cues (Fisher, Hahn, DeBruine, & Jones, 2014). While low levels of adiposity may appear healthy, it might also indicate illness. Low levels of adiposity alongside yellower or redder skin is perceived as much healthier than in faces with reduced coloration and adiposity, suggesting that skin coloration may be a particularly important cue to health (Fisher et al., 2014). Increases in facial temperature are observed with social interactions with members of the opposite sex and may lead to increased redness in the face that may increase attractiveness (Hahn, Whitehead, Albrecht, Lefevre, & Perrett, 2012). Cheek redness increases with higher levels of estradiol (Jones, Hahn, et al., 2015), which is associated with fertility. This cheek redness may then be related to perceptions of health and attractiveness (Samson et al., 2011; but see Burriss et al., 2015). Higher levels of yellowness in facial skin can be caused by carotenoids, which come from a diet rich in fruit and vegetables (Stephen, Coetzee, & Perrett, 2011; Whitehead, Re, Xiao, Ozakinci, & Perrett, 2012). Higher levels of luminance in facial skin (i.e., lighter skin) are also associated with perceived health in both Black South African and Caucasian U.K. faces (Stephen et al., 2011; Stephen, Law Smith, et al., 2009).

There are also social accounts of how skin color may influence health. In Latin Americans, increasingly darker skin is associated with poorer self-reported health, a relationship mediated by exposure to class discrimination and socio-economic status (Perreira & Telles, 2014). Related, lighter skin in women from African and Mexican American samples predicts higher educational attainment and personal income (Hunter, 2002) and skin color is a predictor of chronic stress, blood pressure, and higher body mass index (BMI) in young African American women (Armstead, Hébert, Griffin, & Prince, 2014). These findings suggest social responses to skin affect health and health-related behaviors, which coupled with our skin reflecting our biological health represents a complex interaction in which skin plays a primary role (Jablonski, 2012).

While work on facial health perception has found evidence that overall skin color is a cue for perceived health (Stephen et al., 2011), and that variation in skin color at a fine, textural scale (i.e., skin homogeneity) is also important (Matts et al., 2007), it is not known whether variation in coloration in different parts of the face is a cue to perceived health. The work examining the role of overall skin color in perceived health (Stephen, Coetzee, et al., 2009; Stephen et al., 2011; Whitehead et al., 2012) has utilized point-source measurements from spectrophotometers to measure skin coloration. While this measure accurately captures coloration from a single point (often less than a centimeter), it provides limited information about spatial variation in coloration. Interestingly, many people are dissatisfied with their facial appearance due to uneven coloration. For example, the characteristic redness present in the skin condition rosacea is partially the result of elevated levels of blood flow (Sibenge & Gawkrodger, 1992) and susceptibility to flushing (Wilkin, 1994), and affects health-related quality of life in sufferers (Balkrishnan et al., 2006). Similarly, periorbital circles – or 'dark circles under the eyes' – have a range of causes, such as dermal melanin deposition (Freitag & Cestari, 2007), and are also a cosmetic concern affecting quality of life in individuals of all ages (Roh & Chung, 2009). Moreover, darker coloration in this area is increased by a lack of sleep, which has a negative impact on perceived health (Axelsson et al., 2010). Related, elevated skin yellowness is correlated with health issues such as jaundice (Knudsen & Brodersen, 1989), indicating that healthy coloration (yellowness in the case of jaundice or redness in the case of rosacea) beyond a certain range can be perceived as unhealthy.

Evidence from grooming behaviors suggests that coloration in different facial areas is relevant for health perception. Specifically, there are at least two cosmetics practices that target and improve the appearance of the periorbital and cheek areas. Foundation and concealer are applied to the periorbital region and blush is applied to the cheeks; this is likely a partial cause of faces being rated as healthier with cosmetics than without (Nash, Fieldman, Hussey, Lévêque, & Pineau, 2006). Cosmetics are also related to body image issues, with individuals with higher anxiety and self-presentation concerns wearing more cosmetics (Robertson, Fieldman, & Hussey, 2008). Cosmetics may serve to alter the coloration in the areas that individuals are dissatisfied with, contributing to a healthier appearance, consistent with the notion that a primary function of cosmetics is as a tool for camouflage for decreasing negative self perceptions of attractiveness (Korichi, Pelle-de-Queral, Gazano, & Aubert, 2011).

Based on the cosmetic concerns of those with discoloration in different face regions and the relationships between these discolorations and actual health (Freitag & Cestari, 2007; Roh & Chung, 2009), we hypothesize that the color of particular regions of the skin contribute differently to the perception of health from the face. To test this hypothesis, we began by conducting an exploratory analysis of regional color differences between faces rated as healthy and those rated as unhealthy. We found such differences in the cheek and periorbital regions and confirmed their relationship to perceived health. In a subsequent series of experiments, we manipulated the color of these regions directly to examine whether it would change the perceived health of the faces, implicating the color of these regions as cues for the perception of health from the face.

Study 1

In order to determine whether skin color associated with health varies spatially across the face, we first sought to visualize the differences in color between faces that are perceived as healthy and those perceived as unhealthy. To do this, we compared average images derived from faces perceived as healthy or unhealthy. We utilized a sample of female faces from an older age demographic than is typically used in health perception research, given that we wished to examine a range of healthy appearances. A sample of older women is advantageous as there are likely a wider range of appearances in this age group, reflecting differential life experiences and factors, compared to a relatively homogenous appearance that may be found in younger adult faces. From examination of these difference images, we derived regions of interest and examined whether color values in these areas could predict ratings of health assigned to faces.

Method

The experimental procedures and participant recruitment used in the following study were approved by the Institutional Review Board (IRB) at Gettysburg College.

Models. One hundred and forty six French Caucasian women (56–60 years, $M = 58.10$, $SD = 1.40$) participated as models. All were photographed with a Canon EOS-1 Ds MII camera. Faces were illuminated using diffuse lighting in front and direct flashes from 45° from both sides. All traces of jewelry and cosmetics were removed before models were photographed with a neutral expression, looking directly at the camera. Models were informed before being photographed that their participation was part of a study aiming to increase understanding of the skin and facial appearance related to

Fig. 1. Composite images produced by averaging the faces perceived as the most healthy (left) and least healthy (right).

health. Models were compensated for their participation with €60, as part of a wider range of data collection activities.

Participants and health judgments. Forty members of the Gettysburg College community (30–65 years, $M = 42.83$, $SD = 10.18$, 21 women) rated the models for perceived health and were paid $10 for participation. Participants were recruited through advertisements on campus, and informed they were participating in an experiment investigating the basics of face perception. Participants rated each model for perceived health and were asked 'how healthy is this face?' Responses were indicated via key press on a 1 (*Very unhealthy*) to 7 (*Very healthy*) scale. Participants viewed models in a random order, and images remained on screen until a judgment was made. Stimuli were presented using E-Prime (Version 2.0). Participants were debriefed at the end of the study and informed of the hypothesis.

Exploratory visualization of differences in skin color. To compare the healthy and unhealthy faces, we created a composite of the 12 faces from the set rated as most healthy (average health rating $M = 5.47$, $SD = 0.23$; age $M = 58.42$, $SD = 1.38$), and the 12 rated as least healthy (average health rating $M = 2.89$, $SD = 0.25$; age $M = 58.00$, $SD = 1.59$). These average faces are shown in Fig. 1. These two composites were then shape-normalized by warping both to the geometric mean of the two. We then converted the average images from RGB to CIEL*a*b* color space using MATLAB. This color space consists of three orthogonal dimensions: luminance (L^*), red-green (a^*), and yellow-blue (b^*). The pixel values in each channel can have a maximum value of 255 (L^*, white; a^*, red; b^*, yellow) and a minimum value of 0 (L^*, black; a^*, green; b^*, blue), which differs from traditional CIEL*a*b* values due to the computational representation of signed integer values (see Jones, Russell, & Ward, 2015, for further discussion on computational representations of CIEL*a*b*). For each channel of CIEL*a*b* color space, we subtracted the low perceived health composite from the high perceived health composite, yielding one difference image per channel. This image-analysis based approach effectively illustrates the differences between faces perceived as healthy and unhealthy, and highlights variation across the face that single point measurements (e.g., photometry) cannot identify. These images are illustrated in Fig. 2.

Several things are evident from Fig. 2. In the luminance channel, the healthy looking composite has lighter skin around the eyes and this difference is quite pronounced in the periorbital region (the area under the eyes). The healthy looking composite also has lighter sclera than the unhealthy composite, consistent with differences we have shown elsewhere (Russell, Sweda, Porcheron, & Mauger, 2014). The healthy looking composite possesses redder skin across the forehead, with especially redder skin in the cheek area (a location commonly known as the 'apples' of the cheeks). Finally, the healthy-looking composite has yellower skin overall, with the difference evenly distributed across the face. In order to provide a general scale of the size of the differences between the images, we calculated the normalized Euclidean distance of the difference between images for each channel, defined as the square root of the sum of the squared differences between corresponding pixels in the shape normalized healthy and unhealthy faces. This calculation revealed a gradated increase in difference across color channels, $L^*_{\text{Distance}} = 0.023$, $a^*_{\text{Distance}} = 0.052$, $b^*_{\text{Distance}} = 0.117$. The magnitude of these differences reflects the general dispersal and concentration shown in Fig. 2 – a relatively small and concentrated area for luminance, with more dispersed areas for redness, and a generally large difference for yellowness distributed across the whole face. There are also other differences visible in these images, particularly in the a^* channel, where the nose, lips, and chin appear to be lighter. We interpret these differences with caution, as these differences may arise from registration or alignment errors occurring when warping the faces to a common shape, due to variation in the placement of landmarks across the faces. These kinds of errors, though slight, are more likely to occur around areas with high shape variance (e.g., the mouth) than open patches of skin such as the cheek or forehead, and will give rise to clear artifacts in difference images.

Higher levels of overall skin luminance, redness, and yellowness have been linked to perceived health (Stephen et al., 2011; Stephen, Law Smith, et al., 2009). Our finding that the difference in yellowness between health and unhealthy looking faces is consistent across the entire face supports the results from single-point photometer measurements for assessing yellowness from the cheek and forehead area (Stephen et al., 2011; Whitehead et al., 2012). The relative size of the Euclidean distances (largest for b^*, smaller for a^*, and smallest for L^*) between images is consistent with previous work that illustrates observers add more yellowness to

Fig. 2. Difference images produced by subtracting the composite produced by averaging unhealthy looking faces from the composite produced by averaging healthy looking faces. Subtraction was performed separately in each channel of the CIEL*a*b* color space. From left to right, with normalized Euclidean distances (the square root of the sum of squared differences between image's respective channel): L^* channel, distance = 0.023; a^* channel, distance = 0.052; b^* channel, distance = 0.117. Whiter areas indicate pixels where healthier faces are lighter, redder, and yellower, respectively. For example, in the left image, the pixels around the eyes appear lighter because the healthy composite had higher L^* (luminance) values in that region than the unhealthy composite. Similarly, in the middle image, the pixels in the cheeks appear lighter because the healthy composite had higher a^* (redness) values in that region than the unhealthy composite.

faces for an optimally healthy appearance than redness or lightness (Stephen, Law Smith, et al., 2009). While the distribution of yellowness between faces perceived as healthy and unhealthy was even here, for the luminance and redness dimensions, varying areas of the face were differently related to perceived health.

Confirmatory analysis. The above exploration indicated that different coloration in areas of facial skin seems to vary between faces perceived as healthy or unhealthy, particularly in the periorbital, cheek, and forehead areas. However, there are many ways in which the two averaged images in Fig. 1 differ from one another and we cannot determine from these composite images alone whether the different colorations of the periorbital, cheek, and forehead areas vary consistently with perceived health. Here, we examine the relationship between skin coloration in these three areas and the perceived health of the 146 faces by extracting color values from the aforementioned regions of interest (ROIs) and correlating them with the average health rating for each face. We selected the forehead, periorbital area, and the cheek regions, as illustrated in Fig. 3, for several theoretical reasons. We selected areas that showed clear differences arising from the subtraction of color values from shape-normalized average images of faces perceived as healthy and unhealthy. We also examined areas that were not adjacent to sharp contours on the face where registration errors may have occurred when shape-normalizing the faces, constraining our choice of areas to large regions of skin. We also wanted to examine coloration in areas that are associated with skin complaints that cause dissatisfaction in facial appearance, like the cheeks and forehead (in rosacea; Wilkin, 1994) or the periorbital areas (Axelsson et al., 2010; Roh & Chung, 2009). Finally, examining coloration in areas that have been used as source locations for single point photometry measurement in other studies (Stephen et al., 2011), particularly the cheeks and the forehead, is a useful theoretical step to validate this method of measuring the relationship between health and skin color. These considerations led us to select the three ROIs stated above.

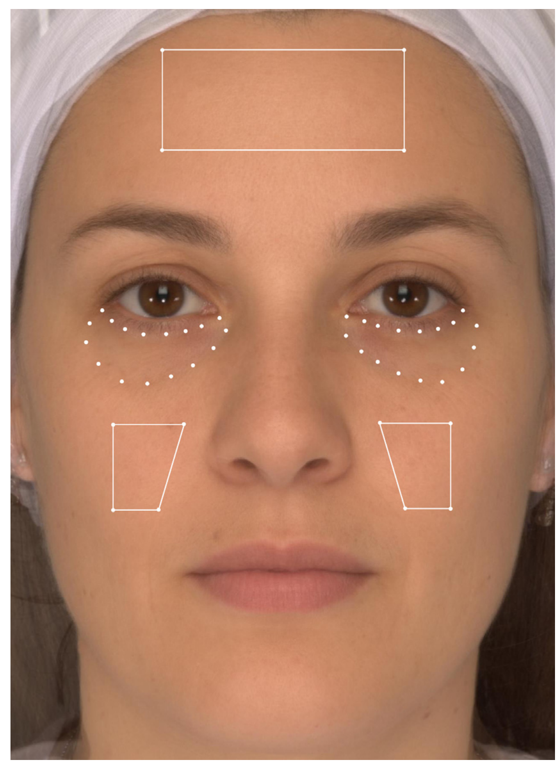

Fig. 3. Regions of interest used to define the forehead, periorbital region, and cheek areas.

Custom MATLAB software was written to allow us to manually delineate the regions and extract the CIEL*a*b* color values from each of the original 146 images. The forehead region was defined as a rectangle, with points placed approximately one quarter and three quarters of the way along the forehead, in line with the pupils. We also labeled the periorbital region starting from the inner corner of the eye, following the contour of the lower lash line extending to the outer corner of the eye, and then following the lower margin of the periorbital region. The left and right cheek areas were labeled with a trapezoidal area that began just above the nostrils and were in line with the inner edge of the iris, and extending out to the outer corners of the eyes, then extending down midway between the nostrils and the lips. Nasolabial folds (i.e., 'smile lines') were avoided when labeling this region as the area can contain shadows that would affect skin color measurement. Labeling of all 146 faces was carried out by the third author to ensure consistency. We averaged pixel values from the periorbital and cheek areas separately to provide a single pixel value, in each color channel, for each of those regions.

Table 1
Relationship between perceived health and color values of regions of interest.

Region of interest	CIEL*a*b* channel	r^2 – variance explained in health ratings	p value
Forehead	L^*	.01	.215
	a^*	.03	.050
	b^*	.04	.021
Periorbital	L^*	.17	<.001
	a^*	.00	.788
	b^*	.05	.009
Cheek	L^*	.01	.218
	a^*	.04	.015
	b^*	.04	.013

Results

We carried out a bivariate Pearson correlation between the averaged perceived health rating for each model, and the color value of each region in each channel. We present r^2 rather than r for these correlations to directly state the proportion of variance in health ratings explained by color in particular facial areas, in Table 1.

For the luminance channel, only the periorbital region had a significant relationship with perceived health, with lighter values being associated with higher ratings of health. Higher redness (a^* channel) in the forehead region was only marginally associated with perceived health, but higher cheek redness showed a stronger positive relationship, reflecting the intensity of the difference in this area between in the a^* channel in Fig. 2. Across all features, greater yellowness (b^* channel) was associated with higher perceived health, with each region contributing a similar amount of variance to judgments of health, consistent with previous work (Stephen et al., 2011) and the observed difference in Fig. 2.

Discussion

We have shown that CIEL*a*b* coloration in the skin is related to perceived health, but the effect of this coloration depends on the area in which it is located. Higher b^* channel values are correlated with health regardless of the region the color was sampled from, fitting both with the difference images shown in Fig. 2, and previous research (Stephen et al., 2011; Stephen, Law Smith, et al., 2009; Whitehead et al., 2012). Of interest here, however, is the link between periorbital luminance (L^* channel) and cheek redness (a^* channel), both of which were positively associated with perceived health. Notably, the reverse was not true: neither periorbital redness nor cheek lightness correlated with perceived health.

The results with periorbital luminance and cheek redness suggest that variation in coloration across a continuous, unbroken skin region can influence perceived health, and is coupled with evidence that these regions may be related to actual health (Axelsson et al., 2010; Roh & Chung, 2009). The adjacent nature of these areas is visible in the left and center faces of Fig. 2, and indicates that a pattern of coloration over a local area of skin contributes to perceived health. This is a novel finding, as the current literature on the relationship between skin color and health perception originates from either the homogeneity of small patches of skin (Matts et al., 2007), the global skin color distribution in shape controlled faces (Fink et al., 2006), or manipulations of the entirety of facial skin based on color values obtained from single point measurements (Stephen et al., 2011). As such, in the following experiments, we focus on the coloration of the cheeks and periorbital regions and their relationship to perceived health, in an attempt to discern whether altering the color of these regions can affect perceived health from the face.

Study 2

We manipulated the L^* values of periorbital skin and the a^* values of skin in the cheek area in a new sample of faces with a much larger age range in order to examine the effect of color in these areas on perceived health. Using a data-driven approach from the results obtained in Study 1, we created a 'healthy' and 'unhealthy' version of each face, by increasing and decreasing the L^* luminance and a^* coloration in the periorbital and cheek regions, respectively. We also created a control condition, in which the locations of the color changes were reversed. That is, there was a version of each face that had redder periorbital regions and a lighter cheek region, and one with greener and darker coloration in those areas. We presented these versions of each face in a forced choice design, presenting the two experimental versions or the two control versions side by side to participants, who selected the face they thought appeared healthier. We predicted that participants would not select either control versions more than the other, but would be significantly more likely to select the 'healthy' experimental version of each face (with lighter periorbital and redder cheek regions) than the 'unhealthy' version (with darker periorbital and greener cheek regions).

Method

The experimental procedures and participant recruitment used in the following study were approved by the IRB at Gettysburg College.

Models and stimulus creation. We photographed a separate sample of 32 French Caucasian women with a wider age range than those in Study 1 (18–52 years, $M = 32.50$, $SD = 11.14$). Models were photographed with the same photographic set up as before, using a Canon EOS-1 Ds MII camera, utilizing a diffuse light in front of the face and direct flashes placed at 45° at either side of the face. Models wore headbands to remove hair from their face if necessary and removed all cosmetics and jewelry. Models maintained a neutral expression while looking into the camera, and faces were later cropped to leave the contour of the face visible. Again, before being photographed, models were informed their participation was part of a study aiming to increase understanding of the skin and facial appearance. Models were compensated for their participation with €40, as part of a wider range of data collection activities.

Image manipulation. We used MATLAB to calculate the L^* values of the periorbital region and the a^* values of the cheek regions in the new sample of faces, using the same definitions for the periorbital and cheek regions, as in Study 1. We then produced two color patches that represented the average periorbital area luminance ± 8 units of L^*. We repeated this procedure for the cheek region, producing two color patches that represented average cheek region color ± 8 units of a^* (Stephen, Coetzee, et al., 2009; Stephen et al., 2011; Stephen, Law Smith, et al., 2009; Stephen & McKeegan, 2010).

For each of the 32 faces, we created masks for the periorbital and cheek regions corresponding to the areas defined in Study 1. To alter perceived health, we manipulated the luminance of the periorbital area by altering the difference between the L^* color patches by ±30% and applying a Gaussian blur at the edges of the masks using JPsychomorph (Tiddeman, Burt, & Perrett, 2001). At the same time, we altered the color of the cheek region by the difference between the a^* color patches, also by ±30%, with another Gaussian blur at the edges. This resulted in two images, one with lightened periorbital areas and redder cheeks (a 'healthy' face) and another with darkened periorbital areas and greener cheeks (an 'unhealthy' face). We applied this degree of change as it maintained a natural appearance

Fig. 4. An example of the experimental manipulation applied to an average face. The left image has a darker periorbital region and greener cheeks, while the right image has a lighter periorbital region and redder cheeks. The right image appears healthier than the left.

for each model, ensuring the manipulation did not appear exaggerated or unnatural. For the L^* channel, the change in luminance applied to each face was in line with approximately half a standard deviation of the distribution of periorbital luminance in the sample, and the change in cheek redness was within approximately 1.35 standard deviations of the distribution of cheek redness. As such, the applied values were well within the range of a normal appearance. The changes in each channel were equal to 4.8 units of L^* and a^*, given that the difference between color patches used for transformation was 16 units, and we applied a change of 30% in either direction. An example of the manipulation is shown in Fig. 4.

We also created an additional two versions of each face to serve as a control condition. To do this, we applied exactly the same transforms to each face, but reversed the location of the transform, resulting in a version of each face that had lighter cheeks and a redder periorbital region (an inverted 'healthy' face) and one with darker cheeks and a greener periorbital region (an inverted 'unhealthy' face). These control images are shown in Fig. 5.

Participants. Sixty-six participants (40 women; 18–22 years, $M = 19.14$, $SD = 1.02$) from Gettysburg College participated in the experiment. Participants were enrolled in an introductory Psychology course and completed the experiment for partial course credit. Participants were debriefed at the end of the experiment and informed of the nature of the manipulation and the hypotheses.

Procedure. We presented participants pairs of faces in a two-alternative forced-choice paradigm, consisting of 64 trials. Our experimental stimuli, the 'healthy' and 'unhealthy' version of each face, were paired together on screen in half of the trials. In the other half of the trials, the two versions of our control stimuli were also paired together. Participants viewed both conditions in a random

Fig. 5. An example of the control manipulation applied to an average face, where the change in coloration is now applied to the opposite area. The left image has a greener periorbital region and darker cheeks, while the right image has a redder periorbital region and lighter cheeks.

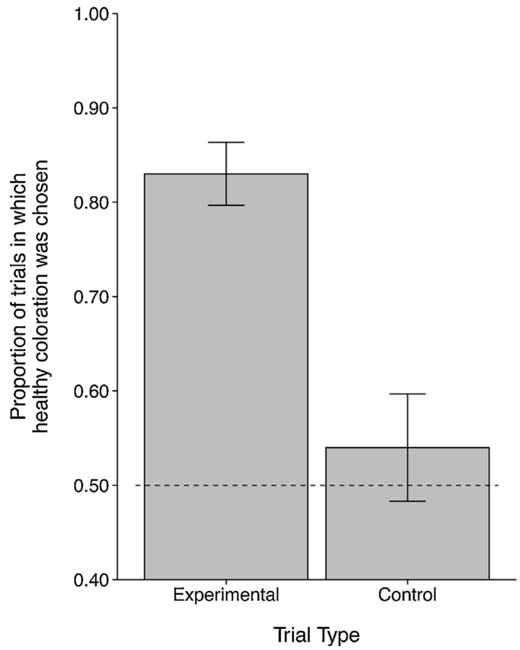

Fig. 6. Proportion of trials in which participants selected the version of each face with higher L^* and a^* values. Experimental trials featured this coloration in the periorbital and cheek regions, while control condition trials featured the coloration in the reverse locations. Error bars represent 95% CI. Faces were paired with a version with reduced L^* and a^* values. The dashed line represents chance performance.

order. The left-right ordering of trials was randomized for each participant, as was the order of trials. For each trial, participants were asked, 'which of these individuals do you think is healthier?', and indicated their response via a mouse click. Images remained on the screen until a response had been made, with an inter-stimulus interval of 500 ms. Stimuli were presented using Python software written with PsychoPy (Peirce, 2007).

Results

For each participant, we calculated the proportion of trials on which they selected the 'healthy' version of each face, and the proportion of trials in which they selected the inverted 'healthy' face, yielding two scores per participant, for the experimental and control trials separately. We analyzed this data using a one-sample *t*-test, comparing the distribution of scores to another with a mean of 0.50, that is, what would be expected by chance. Participants selected the 'healthy' version of each face significantly more often than would be expected by chance ($M = 0.83$, [0.79, 0.86]), $t(65) = 19.05$, $p < .001$, $d = 0.88$. Conversely, for control condition trials, performance was not significantly different from chance ($M = 0.54$, [0.49 0.60]) $t(65) = 1.48$, $p = .143$, $d = 0.08$, indicating no bias in perceiving health for those trials. These results are illustrated in Fig. 6.

Study 3

We have demonstrated thus far that the luminance of the periorbital areas and the redness of the cheeks are positively associated with perceived health, and that female faces with increased coloration in these areas are judged by observers as looking healthier. Importantly, the effect of an increase of these values on perceived health is location specific – a reversal of the location with the same magnitude of change does not result in a clear preference when choosing a healthier version of each face. However, by manipulating both regions at the same time, the separate contribution of the color or luminance of each region becomes conflated. Additionally, a forced-choice design does not indicate an interpretable effect size of a manipulation, only that the manipulated cue is relevant for health perception when all other cues are held constant. In the following experiment, we manipulated the luminance of the periorbital region and the redness of the cheek region separately, and assessed perceived health using a rating scale to determine the effect size of each region's coloration on perceived health.

Method

The experimental procedures and participant recruitment used in the following study were approved by the IRB at Gettysburg College.

Models and stimulus creation. The same models from Study 2 were used for the following study. We applied the exact same manipulation to the faces as in the experimental condition of the previous experiment, but this time only altered one region at a time. This produced four versions of each model; one with a lightened periorbital region and one with a darkened periorbital region, and another two with cheeks that were made redder or greener.

Participants and procedure. A different sample of 57 participants (33 women; 18–22 years, $M = 19.84$, $SD = 1.19$) from Gettysburg College participated in the experiment. Participants viewed all of the faces individually in a random order in a fully within-subjects design, with an additional constraint imposed ensuring they would not see the same identity within five trials of each other, and a 500 ms inter-stimulus interval was included to minimize after effects that may make any manipulation apparent. Participants were asked 'how healthy is this face?' indicating their responses via mouse click on a 1 (*Very unhealthy*) to 7 (*Very healthy*) Likert-type scale. Participants were enrolled in an introductory Psychology course and completed the experiment for partial course credit. At the end of the experiment, participants were debriefed and informed of the nature of the manipulation and the hypotheses. Stimuli were presented using Python software written with PsychoPy (Peirce, 2007).

Results and Discussion

We calculated Cronbach's alpha ($\alpha = .95$) to provide a measure of agreement for health ratings across observers. Given the high level of agreement, we averaged ratings across observers to provide a composite score for each model in each of the four manipulation conditions. We analyzed these ratings using a 2 (Color manipulation: Increased vs. Decreased) × 2 (Region: Periorbital vs. Cheek) repeated measures analysis of covariance (ANCOVA), with the model's age entered as a mean-centered covariate to control for any variation in ratings across age.

There was a significant interaction between color manipulation and region, $F(1, 30) = 15.98$, $p < .001$, $\eta_p^2 = .35$, suggesting perceived health was affected differentially by the color change in either region. This interaction is illustrated in Fig. 7 and discussed below. This interaction qualified the interpretation of the main effect of color manipulation, $F(1, 30) = 38.82$, $p < .001$, $\eta_p^2 = .56$, which indicated that faces with higher luminance or redness were rated as healthier than those with decreased coloration, as well as a main effect of region $F(1, 30) = 19.65$, $p < .001$, $\eta_p^2 = .39$, suggesting faces with any kind of cheek manipulation were rated as healthier than those with a periorbital region manipulation.

The interaction revealed several things regarding the relationship between healthy coloration and different facial regions. The first is that versions of faces with redder cheeks ($M = 4.07$, $SE = 0.12$) and lighter periorbital regions ($M = 4.11$, $SE = 0.13$) are

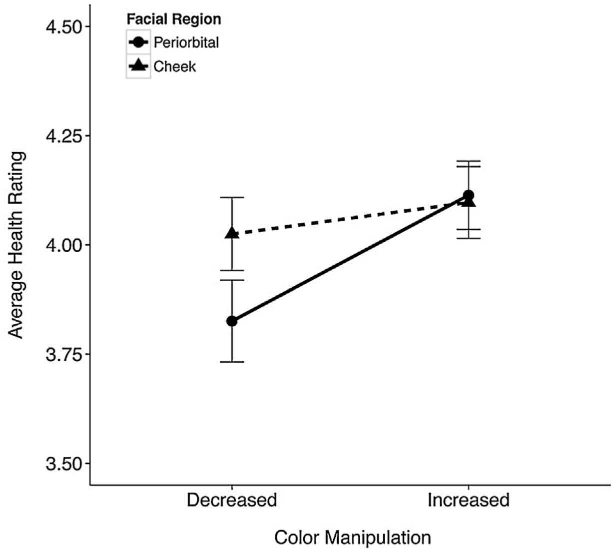

Fig. 7. The interaction between color manipulation and facial regions. Increased color indicates higher periorbital luminance and higher cheek redness, while decreased color indicates lower periorbital luminance and lower cheek redness. Error bars show ±1 *SE*.

rated as equally healthy, $t(31) = 0.49$, $p = .624$, $d = 0.08$. The difference in perceived health from the manipulation of the periorbital region (lightened, $M = 4.11$, $SE = 0.13$; darkened, $M = 3.83$, $SE = 0.13$), $t(31) = 5.84$, $p < .001$, $d = 1.03$, was a larger effect than the manipulation of the cheek area (redder, $M = 4.09$, $SE = 0.12$; greener, $M = 4.02$, $SE = 0.13$), $t(31) = 2.67$, $p = .013$, $d = 0.46$. Finally, while faces were rated as less healthy overall with decreased ('unhealthy') coloration, faces with darker periorbital regions ($M = 3.82$, $SE = 0.13$) were perceived as significantly less healthy than faces with greener cheek regions ($M = 4.02$, $SE = 0.13$), $t(31) = 5.64$, $p < .001$, $d = 0.99$. The age covariate was significant, $F(1, 30) = 40.56$, $p < .001$, $\eta_p^2 = .57$. While this indicated a large effect of age on health perceptions, the covariate did not interact with any other factors (all Fs < 2.46, ps > .127, $\eta_p^2 = .07$), suggesting manipulations of color affected perceived health consistently across the age range.

General Discussion

In an exploratory analysis, we found that faces with the highest perceived health had yellower skin across the entire face, redder cheeks and a somewhat redder forehead, and lighter skin in the periorbital region around the eyes. Examining regions of interest – the forehead, regions under the eyes, and the cheeks – confirmed that lightness under the eyes and redness of the cheeks, as well as overall yellowness, was significantly correlated with perceptions of health. Increasing the lightness of the periorbital regions and the redness of the cheeks made faces appear healthier, while a decrease in either area reduced perceived health. Importantly, when simultaneously manipulating redness in the periorbital region and luminance in the cheeks, we observed no effect on perceived health. Finally, when separating the effects of each region, we found that increased periorbital luminance and cheek redness both contributed to health relative to a reduction in those colorations, but the effect size of periorbital luminance was larger than cheek redness.

Collectively, this work demonstrates that variation in facial skin color – at spatial scales greater than skin texture/skin homogeneity – is relevant to facial health perception, at least in Caucasian female faces. Previous work has shown that manipulating the entirety of facial skin affects perceived health and increased luminance, redness, and yellowness is beneficial for perceived health (Stephen et al., 2011; Stephen, Law Smith, et al., 2009). Our findings show that, for the luminance and red-green channels of CIEL*a*b* color space, the location of color change seems important and could possibly influence findings observed with an entire manipulation of facial coloration. We found no evidence that regional variation in skin yellowness was relevant for health perception. We also did not test formally whether a reversal of the color change would affect perceived health when presented in isolation. That is, increased cheek lightness or periorbital redness may have benefits for perceived health when presented individually (as we did in Study 3 for healthy coloration), and the findings of global increases in these colorations might suggest this (Stephen, Law Smith, et al., 2009). However, we believe that the findings from Study 1 that showed no significant relationships between cheek lightness and periorbital redness, as well as the lack of an effect observed in Study 2, suggest against this possibility, or at least indicate cheek lightness and periorbital redness have much smaller effects than the same coloration in the opposite location.

These findings may also offer an explanation of common cosmetics practices, such as applying blush to the cheeks, or concealer and foundation, to cover dark circles under the eyes. The modification of coloration in these regions by cosmetics that seem targeted to do so may be the reason why faces are perceived as healthier with cosmetics than without (Nash et al., 2006), though the action of cosmetics on producing the appearance of even and unblemished skin likely plays a role (Samson, Fink, & Matts, 2010). The way cosmetics modify the coloration of the cheeks and periorbital region is likely similar to how it modifies other aspects of facial appearance – by exaggerating cues to health and attractiveness.

It is known that overall skin yellowness is a correlate of a diet rich in fruit and vegetables (Whitehead et al., 2012). Are periorbital luminance and cheek redness also valid cues to aspects of actual health? Dark circles under the eyes are exacerbated by a lack of sleep, which affects health over short term time periods (Axelsson et al., 2010). They also increase with age, due to a loss of soft tissue under the skin (Freitag & Cestari, 2007). The cheeks are a location where blood flow is clearly visible in the face and the coloration of oxygenated blood is perceived as healthy (Stephen, Coetzee, et al., 2009). Oxygenated blood is linked with fitness (Armstrong & Welsman, 2001) and deoxygenated blood with illness (Ponsonby et al., 1997). Furthermore, blood flow to the skin is reduced in patients with diabetes (Charkoudian, 2003) and those who smoke (Richardson, 1987), as well as in older adults (Tankersley, Smolander, Kenney, & Fortney, 1991). Because of these lines of evidence, we believe it is likely that these color cues are honest signals of health. It is also possible that the perceptions we have demonstrated here affect individuals' health even further. The complaints people have about their facial appearance in these areas cause distress (Balkrishnan et al., 2006; Roh & Chung, 2009). This may be further compounded by negative appraisal of their facial appearance by others, further illustrating a relationship between social perceptions of facial skin and health, particularly in the case of darker luminance in the periorbital region (Armstead et al., 2014; Perreira & Telles, 2014).

Study 3 showed that periorbital luminance and cheek redness, when manipulated separately, resulted in similar outcomes on perceived health. However, a decrease in periorbital luminance resulted in a greater decrease in perceived health than a reduction of cheek redness. These findings also align with the findings of Study 1, where periorbital luminance explained a larger portion of variance than did cheek redness. Study 3 suggests that darker periorbital regions account for much of the variation in health ratings. It is unclear why periorbital luminance has a larger effect than cheek redness on perceived health. Dark circles have been linked to the appearance of tiredness, sadness, or even being hung-over and are a concern for individuals of all ages (Roh & Chung, 2009). Conversely, cheek redness may reflect cardiovascular health (Stephen, Coetzee, et al., 2009), or more stable aspects of biological health. Perhaps the luminance of the periorbital region reflects health over short-term periods, which may be relevant in attractiveness or mate choice judgments. As such, darkness of the periorbital region might be viewed more negatively as it is a cue to recent activities that impact health (such as lack of sleep). An alternative account is that the larger role of periorbital luminance in health perception is related to age perception. The periorbital area is a location that may be implicated in facial contrast, a cue to femininity (Russell, 2009) and age (Porcheron, Mauger, & Russell, 2013). Facial contrast declines with age and faces appear older with lower contrast (Porcheron et al., 2013). However, the luminance contrast of the eyes, most closely related to the periorbital luminance manipulated here, are not a significant predictor of perceived age, which contradicts this alternative account. Further, increased luminance contrast around the eyes is positively related to perceived health (Russell et al., in press), but not age (Porcheron et al., 2013). Because periorbital luminance is closely related to luminance contrast around the eyes, this suggests that periorbital luminance is related to perception of health but not age. Also, other studies have found that while dark circles under the eyes predict perceived age, they are a very weak predictor (Nkegne et al., 2008), suggesting that perceived age does not play a large role in how health is perceived using periorbital luminance.

We have shown that faces perceived as healthy possess lighter skin under the eyes, and redder cheeks. Manipulating this coloration causes faces to be perceived as healthier, but only if the coloration is increased in the specific areas. While lighter periorbital regions and redder cheeks improve perceived health, darker periorbital skin decreased perceived health most severely. These findings indicate that, for at least female Caucasian faces, periorbital luminance and cheek redness are cues to health, demonstrating that regional variation in skin color is relevant to facial health perception. These findings also indicate that cosmetic concerns about certain facial areas have a basis in reality, and that variation in coloration in these areas does contribute to differing perceptions by others.

Author Contributions

Conceived and designed experiments: AJ, AP, FM, RR. Performed the experiments: AJ, JS. Analyzed the data: AJ, JS. Collected and contributed materials/stimuli: AP, FM. Wrote the paper: AJ, AP, RR.

Conflict of Interest

The authors declare no competing interests in the design or decision to submit the research for publication.

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