Sclera Color Changes With Age and is a Cue for Perceiving Age, Health, and Beauty

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Abstract

Redness or yellowness of the sclera (the light part of the eye) are known signs of illness, as is looking older than one's actual age. Here we report that the color of the sclera is related to age in a large sample of adult Caucasian females. Specifically, older faces have sclera that are more dark, red, and yellow than younger faces. A subset of these faces were manipulated to increase or decrease the darkness, redness, or yellowness of the sclera. Faces with increased sclera darkness, redness, or yellowness were perceived to be older than faces with decreased sclera darkness, redness, or yellowness. Further, these manipulations also caused the faces to be perceived as more or less healthy, and more or less attractive. These findings show that sclera coloration is a cue for the perception of age, health and attractiveness that is rooted in the physical changes that occur with age.

Keywords: face perception, signs of aging, attractiveness, eye, visual appearance

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We care about how old we look, and for good reason. It matters. Age is a major dimension of human social interaction and person perception (Uleman, Saribay, & Gonzalez, 2008), and the face is a major source of information about a person's age (Zebrowitz, 2006). How old we look influences how others treat us (Zebrowitz & S.M., 1991; Zebrowitz, Tenenbaum, & Goldstein, 1991). Yet the importance of how old we look is not limited to how others interact with us. Apparent age is closely related to health among older adults. Looking old or young for one's age (even when assessed from static facial photographs) is associated with health and environmental factors such as body mass index (BMI), depression, marital status, and social class (Mayes et al., 2010; Rexbye et al., 2006). Perceived facial age is a clinically useful biomarker of aging (Christensen, Thinggaard, McGue, Rexbye, & Hjelmborg, 2009), and looking older than one's age is a sign of poor health (Bulpitt, Markowe, & Shipley, 2001; Hwang, Atia, Nisenbaum, Pare, & Joordens, 2011). Indeed, among older adults the mere appearance of age predicts how long a person will live. People who look old for their age die sooner (Christensen et al., 2004; Dykiert et al., 2012). How old we look is a matter of grave importance. Discovering the cues upon which perceived age relies could help reveal the mechanisms linking rated age and mortality. This would in turn aid our understanding of the aging process and the development of interventions for encouraging healthy aging.

Perception of health and perception of age rely on partially overlapping cues. Some cues for the perception of age are also cues for the perception of healthiness, such as the homogeneity of skin reflectance (e.g. the absence or presence of dark spots and other pigmented irregularities) (Fink, Grammer, & Matts, 2006). However, some cues to age are only weakly related to health, such as wrinkling of the skin (Fink & Matts, 2008), and some cues to healthiness are weakly related to age, such as overall skin color (Stephen, Coetzee, Law Smith, & Perrett, 2009; Stephen, Coetzee, & Perrett, 2011).

Age and health are also major factors in the perception of attractiveness. Older faces are rated as less attractive than younger faces, and more attractive faces are estimated to be younger than less attractive faces of the same age (Ebner, 2008; Foos & Clark, 2011; Kwart, Foulsham, & Kingstone, 2012). On the basis of theoretical grounds (Symons, 1979; Thornhill & Gangestad, 1999), it is believed that health should also be predictive of beauty, though empirical support for this idea is mixed (Weeden & Sabini, 2005). Regardless, visual cues that change with age are likely to be related not only to the appearance of age but also to the appearance of health and beauty. In the present work we will provide such an example.

There are numerous physical changes in the face that occur with age. Cessation of growth occurs at approximately 20 years of age, but face shape continues to undergo changes through adulthood, particularly in the later years (Farkas et al., 2004). Facial skin undergoes dramatic changes through adulthood, including wrinkling and sagging (Burt & Perrett, 1995; George & Hole, 1995; Mark et al., 1980; Samson, Fink, Matts, Dawes, & Weitz, 2010) increases of pigmented irregularities, and skin color changes such as decreased homogeneity of skin reflectance (Fink et al., 2006; Matts, Fink, Grammer, & Burquest, 2007).

The internal features of the face also change with age and are relevant for age perception. With photographs of the same individual obtained at two different ages, George and Hole substituted features between the photographs (George & Hole, 1998). Transplanting older features into a younger face increased age estimates by approximately 40%, the opposite decreased the age of the older face by approximately 33%. Both internal feature size and shape influence age perception. Large and round eyes in real faces as well as shorter noses decrease the estimated age of the person (Berry & McArthur, 1986). Lip height and border definition decrease with age and are visual cues for age perception (Gunn et al., 2009; Nkengne et al., 2008). Recently we have shown that facial contrast—the contrast between the eyes, eyebrows, lips and the skin that surrounds them—decreases with age in adults and is a cue for perceiving the age of a face (Porcheron, Mauger, & Russell, 2013). This finding was consistent with the possibility that parts of the eye become more red and yellow with age.

The sclera and conjunctiva are visible in the white part of the eye and their appearance help support perception of a person, such as aspects of their health. Yellowness of the sclera is associated with liver pathology (Roche & Kobos, 2004) and apparent redness of the sclera occurs when blood vessels in the overlying conjunctiva become dilated, a result of irritation produced by allergy, fatigue, or infection, as well as a wide range of ocular diseases (Leibowitz, 2000; Murphy, Lau, Sim, & Woods, 2007). Redness of the sclera has recently been found to be a cue for judgments of facial beauty, with artificially reddened sclera being rated less attractive than unmanipulated versions of the same images (Provine, Cabrera, Brocato, & Krosnowski, 2011).

Sclera coloration is also related to age. A recent study by Grundl and colleagues (2012) using photographs of 60 Caucasian women aged 15-65 years age found that the saturation of the sclera is positively correlated with age, while the brightness of the sclera is negatively correlated with age. This means that the overall ‘whiteness’ of the sclera decreases with age. The decreasing whiteness of the sclera with age is likely a result of multiple factors, including increased lipid deposits (Fraunfelder, Garner, & Barras, 1976; Watson & Young, 2004) and yellowing caused by changes of the elastic fibers in the conjunctiva due to cumulative sun exposure (Gründl et al., 2012). As described above, reddening of the eyes is a result of a wide variety of causes that result in dilation of the blood vessels of the conjunctiva (Provine et al., 2011). It seems plausible that cumulative lifetime experience of these pathologies could result in an increased baseline level of redness in older eyes. In the Grundl et al. 2012 study, participants rated the perceived age and attractiveness of the faces whose scleral color had been measured. Significant negative correlations were found between saturation of the sclera and attractiveness and perceived age, and between brightness of the sclera and perceived age. Because the study was correlational rather than experimental we cannot distinguish between the possibility that participants actually used sclera color as a cue for perceiving age and attractiveness and the possibility that they used other cues such as wrinkles around the eye, graying of the eyebrow, eye size, etc. that are correlated with both age and sclera color.

In the present work we tested the hypotheses that sclera color changes significantly with age, and is used as a cue for perceiving age, health, and beauty. In the first study, we measured the color of the iris and sclera in a set of 286 facial images of Caucasian women aged between 20 and 70 years old, finding that sclera color changes with age. In particular, older faces have sclerata that are darker, redder, and yellower than younger faces. In the second study we manipulated sclera coloration to determine whether it is causally related to perceived age, health, and attractiveness. Each of thirty faces was manipulated to create new versions of the face in which the color of the sclera were artificially manipulated. In a forced-choice paradigm, participants were shown both modified images and instructed to determine which face looked younger, healthier, or more attractive.

Study 1

Method

Full face images of 286 French Caucasian women with healthy skin between 20 and 70 years old (40 faces from 20 to 29, 60 faces from 30 to 39, 71 faces from 40 to 49, 60 faces from

50 to 59 and 55 faces from 60 to 70) were acquired using a closed photographic system that allows accurate and reproducible positioning of the subjects as well as controlled lighting conditions. These same images were used in Study 1 of (Porcheron et al., 2013).

The height of the camera (Canon EOS-1 Ds Mark II, 17 MP) was adjusted to the height of the face. Each face was illuminated by three flashes: one in front of the face (diffuse light), the height of this flash was adjusted to the height of the subject's face; and two flashes illuminating the face with a 45 angle (direct light), the height of these flashes was fixed. These lighting conditions were defined in order to avoid cast shadows and to minimize variation from shading on the faces. The subjects wore no make-up or adornments, their eyes were open, and they were asked to keep a neutral expression and gaze directly into the camera. Faces wearing permanent make-up or colored contact lenses were not included.

Because this was a cross-sectional study, it was important to determine whether any variation of eye color with age could be due to differences in iris color between the younger and the older women of our sample. Toward this end, the iris color of each face was evaluated using the system described by Seddon et al. (1990) in which eyes are categorized into five grades, from 1 (very light) to 5 (very dark). We grouped together grades 1 and 2 (lighter eyes) and grades 3 to 5 (darker eyes), and analyzed the difference in eye color between the older and younger faces in our set of images with a χ^2 test. There was no significant difference in iris color between the different ten-year age classes (χ^2= 2.46, p = 0.6515).

The labeling of facial regions and the measurement of the contrast was performed using MATLAB 7.8.0 (R2010a). The general approach was similar to that of (Russell, 2009) and (Porcheron et al., 2013), but the regions of the face that were labeled were different. Here each image was individually labeled to define regions corresponding to the sclera, the iris, and the pupil. Examples of the eye region labeling can be seen in Figure 1. Each eye contained two or three specular reflections from the studio lights. One of these reflections came from a large rectangular diffusion head, and was partially overlapping the pupil. In the labeling procedure, this specular reflection was included in the definition of the pupil. The iris was defined as the pixels inside the outer border of the iris, but excluding the pixels within the pupil. There were additional specular reflections that were small spots produced by reflections of the two direct unfiltered lamps described above. In most faces there were two of these reflections in each eye but in some faces there was only one, as in Figure 1, because the nose blocked the illumination from one of the lamps. The number of specular reflections (one or two) did not vary with the age of the face. These small specular reflections were removed in post-processing by removing all pixels above a fixed luminance threshold that was determined to remove the specular reflections but not any of the other parts of the image.

To measure the luminance and color of the eyes we used the CIE *L*a*b** color space which corresponds roughly to the color channels of the human visual system. *L*a*b** color space was designed such that differences between coordinates of stimuli are predictive of perceived color difference between the stimuli (Brainard, 2003). The three orthogonal dimensions of this color space are light-dark (*L**), red-green (*a**), and yellow-blue (*b**).

The values of all the pixels within the iris and within the sclera were averaged separately for each of the three color dimensions. Thus, for each face we calculated six values: the average *L** (luminance or light-dark) value within the iris and within the sclera, the average *a** (red-green) value within the iris and within the sclera, and the average *b** (yellow-blue) value within the iris and within the sclera. The values can range from 0 (black for *L**, green for *a**, blue for *b**) to 255 (white for *L**, red for *a**, yellow for *b**). A descriptive analysis of sclera and iris color was performed and the relationships between age and the coloration of the sclera and iris were tested using analysis of variance models with (Seddon grade) eye color as a covariate (Jobson, 1992). Interactions terms were tested and significant one were kept in the final model. We used an alpha level of 0.05 for all statistical tests, and 0.07 for tendencies.

Results

The effect of age on luminance and color, with eye color as a covariate, are presented in Figure 2 and Table 1. It is readily apparent from Figure 2 that sclera color varies with age much more than does iris color. Coloration of the sclera differed significantly as a function of age in all three color channels. The L^* values of the sclera decreased with age, a^* values increased, and b^* values increased, meaning that the older faces had sclerata that were darker, redder, and yellower than the younger faces. In addition to the relationships between age and sclera color, there were small relationships between the eye color (Seddon grade) and sclera luminance and redness, with lighter eyes (i.e. blue and hazel eyes) having sclera that were lighter and more red than those of darker eyes (i.e. brown eyes).

In contrast to the robust relationships between sclera color and age, iris color was weakly related to age. The L^* and a^*values of the iris were slightly but significantly correlated with age, with the older faces have irides that are slightly lighter and redder than those of the younger faces. There was not relationship between b^* value of the iris and age. As would be expected, there were very large effects of eye color (Seddon grade) on measured iris color in all three color channels. Faces with light eyes (i.e. blue and hazel) had irises that were lighter, greener, and bluer than dark eyes (i.e. brown eyes). For the a^* and b^* channels there were significant interactions between the age of the face and the eye color; the increase in the a^* values of the iris with age occurred only in the light colored eyes, and there was a decrease in the b^* values of the iris with age in the dark eyes only. However, when eye color was *not* taken into account the effects of age on the *a** and *b** values of the iris went away completely ($F(1,285) = 1.03$, $p = 0.31$; $F(1,285) = 0.09$, $p = 0.76$ respectively), and so we are inclined to believe that there is not a meaningful change with age in the redness or yellowness of the iris (all other effects including that of age on iris *L**were the same when eye color was not taken into account).

Studies 2a and 2b

In the second study we manipulated sclera coloration to determine whether it is causally related to age perception. Because of the close relationship between the perception of age and the perception of health and attractiveness, we also investigated the role of sclera coloration in the perception of health and attractiveness. The two versions of the study used the same stimuli and procedure, and differed only in terms of the participants. Study 2a used a sample of undergraduate students and Study 2b used a sample of middle aged adults. Faces were manipulated to increase or decrease the *L**, *a**, and *b** values of the entire sclera region. A forced-choice design was used in which participants directly compared the two versions of the same face with increased or decreased sclera, and indicated which face looked younger, healthier, or more attractive.

Methods

Thirty full-face images were selected from the set of 286 used in Study 1 in order to have 10 faces of women 23 to 34 years old, 10 faces of women 35 to 44 years, and 10 faces of women 45 to 59 years. These were the same faces used in Porcheron et al. (2013) Study 3.

Using Adobe Photoshop®, the *L**, *a**, and *b** values of the entire sclera region were individually increased or decreased. For instance, increasing the *a** value of the sclera made it more red, while decreasing the *a** value made the sclera more green. In addition to creating versions of the face with each channel manipulated individually, we also created a version of each face in which all three channels were manipulated. To make these versions, the *L** value was increased while the *a** and *b** values were decreased, or the *L** value was decreased while the *a** and *b** values were increased. In this way the three channels were manipulated simultaneously in the directions typical of older or younger faces, as found in Study 1. The magnitude of the manipulation was the same for each face, and was determined with the goals of maximizing the effect of the change on apparent age while maintaining a naturalistic appearance in all the faces. No part of the face other than the sclera was changed (e.g. the iris was not manipulated). The features were defined as described in the Study 1. Only the manipulated faces were presented to the participants. Example stimuli are shown in Figure 3.

For each of the four versions of the 30 stimulus faces, participants saw the versions with increased and decreased sclera values presented side-by-side and indicated with a button press which of the two looked younger, healthier, or more attractive. All participants made all three ratings, the order of which was counterbalanced across participants. The sequence of identities was counterbalanced for age and randomized for each participant, and the left-right ordering of increased/decreased sclera values was counterbalanced.

Twenty-seven Gettysburg College undergraduate students (18 to 23 years, M = 20.5 years; SD = 1.4; 13 females) participated in Study 2a. These subjects received course credit for participation. Forty adults from the community (29 to 71 years, M = 46.5 years, SD = 11.3 years; 24 females) participated in Study 2b. These subjects received $10 for participation.

Study 2a Results

The results from Study 2a with young adult participants are shown in Figure 4a. In the vast majority of trials the face with lighter, greener, or bluer sclera was selected as appearing younger, healthier, or more attractive, whatever the channel manipulated. This massive effect of the manipulation shows clearly that sclera color, in all three color channels, plays a role in the perception of age, health and attractiveness.

Following the primary finding of an effect of sclera color on perceived age, health, and attractiveness, we sought to determine whether this effect varied as a function of the particular color channel that was manipulated, the age of the face, and the gender of the raters. Because it was a forced-choice task, each dependent variable is binomial (subjects selected either the high or low contrast version of the face), and so we performed a factorial logistic regression model with repeated measurements to investigate the effect of color channel, age of face, and gender of rater as fixed effects on the likelihood of choosing the high contrast version of the face, with faces and participants as repeated random effects. Separate but identical models were used for each of the three dependent variables (age, health, and attractiveness). Because participants evaluated several faces, and faces were evaluated by several participants, we used the method of generalized estimating equations (GEE) to account for correlations among observations from the same participant and also of the same face. Liang and Zeger (1986) introduced GEE as a method of dealing with correlated data when the data can be modeled as a generalized linear model, such as correlated binary and count data. The GEEs provide a practical method with reasonable statistical efficiency to analyze correlated data arising from repeated measurements, as the normality assumption is not accurate when the responses are discrete and correlated. The GEE method estimates the regression parameters assuming that the observations are independent, uses the residuals from this model to estimate the correlations among observations from the same face or from the same participant, and then uses the correlation estimates to obtain new estimates of the regression parameters. This process is repeated until the change between two successive estimates is very small. Associations were expressed as adjusted odds ratios (AOR) together with their 95% confidence interval (95% CI) estimate (Jobson, 1992).

There was a significant main effect of the color channel manipulated for each of the three Dependent Variables (DV), as is apparent in Figure 4a and detailed in Tables 2 to 4 (Supplementary Online Material). The largest effects were found for the manipulation of all three color channels together (*L*a*b** condition), followed very closely by the *b** condition, followed by the *a** condition, followed by the *L** condition.

There was no significant main effect of age of the face, but there was a significant interaction between the color channel manipulated and the age of the face, for each of the three DV, with lower differences between the channels for the middle aged faces. For the DV of attractiveness, when the *L** channel was manipulated there was a larger effect of the manipulation in the younger faces than in the older faces, while when the *a** channel was manipulated there was a larger effect of the manipulation in the older faces than the younger faces. For the DV of health, when the *a** channel was manipulated there was a larger effect of the manipulation in the older faces than in the younger faces.

There was a significant main effect of the gender of the raters for each of the three DV, with female raters showing larger effects of the manipulation than male raters. For only the DV of health perception there was a significant interaction between the gender of the rater and the color channel manipulated because there was no difference between the effect of the manipulation for male and female raters in the *L** condition, and also because female but not male raters showed a larger effect of the manipulation of all three color channels together (*L*a*b** condition) compared to *L** channel.

Study 2b Results

The results from Study 2b with middle aged participants are shown in Figure 4b. In the vast majority of trials the face with lighter, greener, or bluer sclera was selected as appearing younger, healthier, or more attractive, regardless of the channel manipulated. As in Study 2a, this massive effect of the manipulation shows clearly that sclera color, in all three color channels, plays a role in the perception of age, health and attractiveness. To determine whether the effect of the manipulation varied as a function of the color channel manipulated, the age of the face, and the age and gender of the raters we performed the same statistical analyses as in Study 2a, for each of the three DV.

There was a significant main effect of the color channel manipulated for each of the three DV, as is apparent in Figure 4b and detailed in Tables 5 to7 (Supplementary Online Material). The largest effects were found for the manipulation of all three color channels together (L*a*b* condition), and the smallest for the *L** condition.

There was no significant main effect of age of the face for each of the three DV. However, for the DV of health there was a trend toward a larger effect of the manipulation on older faces than younger faces. For only the DV of attractiveness there was a significant interaction between the color channel manipulated and the age of the face that was similar to that seen in Study 2a.

There was a significant effect of the gender of the raters for the DV of age perception (but not health and attractiveness), with female raters showing larger effects of the manipulation than male raters. For the DV of age and attractiveness, but not health, there was a significant interaction between the color channel manipulated and the gender of the raters. For the DV of age, female raters showed a stronger effect of the manipulation in the *L** and *a** condition only.

For the DV of attractiveness, female raters showed a stronger effect of the manipulation in the *L*a*b** condition only.

Studies 2a and 2b: Discussion

The broad pattern of results in the two versions of Study 2 was nearly identical, as can be appreciated by comparing the results in Figures 4a and 4b. In both versions participants selected the faces with sclera that were less dark, yellow, or red sclera as being younger, healthier, and more attractive at levels well above chance. This means that with both a participant sample of young adults and a participant sample of middle aged adults there were clear effects of manipulating sclera color on perceived age, health, and attractiveness. Differences in the results of the two versions were minor. There were larger differences across the different color channels in the effect of the manipulation in the young adult sample than in the middle aged sample, as can be appreciated by comparing Figures 4a and 4b, or by comparing the AORs for the color channel comparisons in Study 2a and Study 2b in Tables 2 to 7 (Supplementary Online Material).

Collectively, these results show that faces with sclera that are darker, redder, and yellower appear older, less healthy, and less attractive, and that faces with sclera that are lighter, greener, and bluer appear younger, healthier, and more attractive. This was found for faces ranging in age from 20 to 59, with a sample of participants aged 18 - 23 and also with a separate sample of participants aged 29 – 71.

General Discussion

In study 1 we found support for the hypothesis that sclera coloration changes with age. In faces ranging from 20 and 70 years old, there were significant correlations between sclera color and age, with older faces having sclera that were darker, redder, and yellower than younger faces. There was also a much smaller but also significant correlation between iris luminance and age, with older faces having irides that were slightly lighter than younger faces. In study 2 we found support for the hypothesis that sclera coloration plays a role in the perception of the age, health, and attractiveness. Faces with sclera manipulated to be lighter, greener, or bluer were selected as appearing younger, healthier, and more beautiful than the same faces with sclera manipulated to be darker, redder, or yellower. These results demonstrate that sclera color is used as a cue for perceiving the age, health, and beauty of faces.

The discovery that sclera color is a cue for perceiving age from the face adds to our knowledge about how perceived age is computed by the visual system. Perceived age is a robust biomarker of aging (Christenson et al. 2009) that is predictive of mortality (Dykiert et al. 2012). Among biomarkers of aging, perceived age may be particularly useful because it is measured non-invasively. Further, perceived age can be broken into distinct component cues such as wrinkles, sagging, decreased skin homogeneity, and now sclera color. It is not known how particular component cues to perceived age are weighted by the brain’s visual system to calculate perceived age, or whether these cues have independent relationships to mortality or to particular aspects of health. By identifying a new cue to age perception we have also identified a candidate biomarker of aging, which holds the potential to illuminate the mechanisms linking rated age and mortality, thereby shedding light on the aging process.

Sclera color was found to be related not only to perceived age, but also to perceived health and attractiveness. Indeed, in Studies 2a and 2b the effect of sclera manipulation on the three independent variables was nearly identical. This high degree of similarity between the different measures was likely due in part to demand characteristics of the forced-choice design. With only a single cue (sclera color) differing between the two response options, subjects likely made their responses to the three different questions on the basis of similar information. Subsequent work with alternate methods would be useful in this regard. However, demand characteristics are at most a partial explanation because the perception of age, health, and attractiveness are known to be related, and because sclera color is already known to be related to health and attractiveness.

To what degree are the perception of age, health, and attractiveness linked? It could be argued that the effect of sclera color on perceived age, health, and attractiveness was so similar because these variables are functionally identical. However, this “strongly linked” interpretation is undercut by examples from the literature where perceived health is not linked with perceived age (Fink & Matts, 2008) or attractiveness (Weeden & Sabini, 2005), suggesting that the three judgments, while closely related, are not identical and do not necessarily rely on the same cues or processes. A more plausible interpretation is that the three judgments are linked via underlying physiological factors. Fink and colleagues have observed that skin color distribution affects the perception of age, health, and beauty, and argued that they may signal aspects of the underlying physiological condition of a person that are relevant for mate choice (Fink et al., 2006). A similar situation may exist with sclera color, given the known links between health and sclera color, particularly the yellowness and redness of the sclera. It is plausible that the same health-related factors that cause transitory changes in sclera color also cause the changes in sclera color with age. In other words, the age-related changes in sclera color that we have observed here may be due in part to cumulative lifetime exposure to those factors that change sclera color temporarily—e.g. yellowness caused by liver dysfunction and redness caused by inflammation, sleep loss, etc. Future work could test this hypothesis by determining whether people with greater lifetime exposure to factors that cause short-term sclera color changes also experience larger changes in sclera color with age.

The present results support and extend recent work on sclera coloration. Study 1 loosely replicated the finding by Gründl et al. (2012) that the sclera becomes darker and more saturated (i.e. less white) with age, but using a different color space and a larger set of faces, while study 2 extends this work by showing experimentally that sclera coloration is used as a cue for perceiving the age, health, and beauty of the face. This also replicates the finding by Provine et al. (2011) that increased scleral redness makes a face appear less attractive, and extends it by demonstrating that increased scleral darkness and yellowness also make faces appear less attractive, as well as older and less healthy. Together with these other findings, our discovery sheds light on the practice of retouching photographs by whitening the sclera. In particular, our findings support the idea that this is not an arbitrary practice due only to fashion, but rather that it manipulates a biologically-based cue for perceiving the age, health, and beauty of a face. An interesting direction for future research would be to determine whether there is an optimal color for the sclera, and whether that optimal color varies as a function of factors such as the age of the face, the color of the iris, the color of the surrounding skin, or other facial features.

These results are also relevant to the recent finding that the thickness of the limbal ring (the annulus at the edge of the iris that is often darker than then interior of the iris) decreases with age and that faces with darkened limbal rings are rated as more attractive than unmanipulated faces (Peshek, Semmaknejad, Hoffman, & Foley, 2011). In particular, our results support the suggestion of Peshek and colleagues that dark limbal rings may be attractive because they induce a brighter appearance in the sclera (p. 143), by showing that a brighter sclera is indeed perceived as more attractive, as well as younger and healthier. In complementary fashion, corneal arcus (arcus senilis)—a light opaque ring in the corneal limbus caused by phospholipid deposits that is commonly found in older adults (Ang et al., 2011)—likely reduces local contrast between the iris and sclera, making the sclera appear darker and the face appear older.

Our finding of no relationship between age and iris *a** and *b** color when not taking account eye color, and a weak but significantly positive relationship between age and iris luminance replicates previous work finding that iris coloration rarely changes once adulthood is reached, though luminance does increase slightly with age in some eyes (Bito, Matheny, Cruickshanks, Nondahl, & Carino, 1997; Imesch, Wallow, & Albert, 1997). Further, the finding serves as an important control by indicating that the relationship between sclera color (particularly sclera luminance) and age cannot be due to differences in shading/illumination of the eye among faces of different age.

The finding that sclera redness and yellowness increases with age also explains a part of our previous finding that facial contrast decreases with age (Porcheron et al., 2013). In that study we found that contrast between the eye and the surrounding skin in the *a** and *b** channels decreased with age. Because the skin has higher *a** and *b** values than the eyes (i.e. the skin is more red and yellow than the eyes), increased *a** and *b** values in the eye result in lower *a** and *b** contrast between the eye and the surrounding skin. Here we have shown that eye color does indeed change with age to become more red and yellow, and specifically that it is the sclera but not the iris that becomes more red and yellow with age. This indicates that part of the change in facial contrast with age is due to the changes in sclera color.

This comparison with other cues to age perception raises the question of the relative importance of sclera color for perceiving age. The fact that the same face with different sclera coloration can appear older or younger (as in Figure 3) indicates clearly that sclera color is a cue to age. However, the fact that this cue has been “staring us in the face” all our lives and yet is only now being discovered suggests that it is a relatively small cue for age perception. Cues such as wrinkles and sagging, which are known even to small children as signs of aging, are presumably much larger cues for age perception than sclera color.

Because older faces have darker sclerata, but irides that are slightly lighter, the contrast between the iris and sclera is reduced in older faces relative to younger faces. Among the primates, this contrast is unique to humans (Kobayashi & Kohshima, 1997, 2001), and is believed to play an important role in the perception of gaze direction (Ando, 2002; Sinha, 2000), as is the contrast between the sclera and the surrounding skin (Ando, 2004). We have indirectly shown here and elsewhere (Porcheron et al., 2013) that the contrast between the sclera and the surrounding skin decreases with age. The decrease with age in the contrast between the sclera and the iris and between the sclera and surrounding skin suggests the possibility that it is harder to detect the gaze direction of older faces. Additionally, contrast between the iris and sclera and contrast between the eyes and surrounding skin may be important for face recognition in both infants (Farroni et al., 2005; Otsuka et al., 2013) and adults (Bruce & Young, 1998; Gilad, Ming, & Sinha, 2009). The decreases in these forms of contrast that we have shown to occur with age suggest the additional possibility that older faces are more difficult to recognize. Some evidence for this hypothesis can be found in the observation that the own-age bias is smaller for older adults than younger adults (Rhodes and Anastasi (2012), Table 8). Difficulties in recognizing or detecting the gaze direction of older faces may be exacerbated further by the decrease in eye size that occurs with aging (Berry & McArthur, 1986; Burt & Perrett, 1995). In the dataset described in Study 1, we observed negative relationships between measured sclera size and age (r_{286} = -

0.42, $p < 0.0001$) and between measured iris size and age ($r_{286} = -0.44$, $p < 0.0001$), indicating that both parts of the eye are smaller and presumably less visible in older faces. Aside from the sclera's reduced contrast with surrounding structures, its diminished size may further reduce its salience for the perception of gaze direction. If perceptibility of gaze direction or ease of recognition is lower for older faces, it could have a negative impact on rapport achieved between older adults and other people, in a fashion analogous to that implicated by recent work showing that facial expressions of emotion are harder to recognize in older adults (Hess, Adams, Simard, Stevenson, & Kleck, 2012). In general, the social perceptual implications of age and health related changes in the sclera will be an interesting topic for future research, for example to determine whether judgments of warmth, dominance, strength, trustworthiness, guilt, or employability vary as a function of sclera color.

Conclusion

We have found that the color of the sclera is related to age, with older faces having sclera that are darker, redder, and yellower than younger faces. Further, we have shown that sclera coloration is used as a cue for perceiving the age of the face; images of faces manipulated to have darker, redder, or yellower sclera were perceived as older than images of the same faces manipulated in the opposite way. An important caveat of these findings is that we only investigated female Caucasian faces from 20 -70 years of age. Though there is no particular reason to expect different results with other racial groups or with males, additional work will be necessary to determine conclusively whether sclera color changes with age and is used as a cue for perceiving the age, health, and beauty of faces other than adult Caucasian females.

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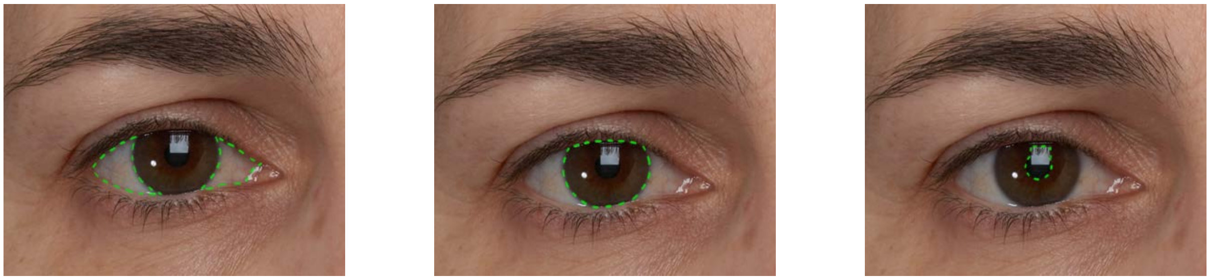
Table 1. Effects of faces' age and eyes color on sclera and iris color – analyses of variance.

Dependent variable	***Variables***	***MS***	***SD***	***F (1,285)***	***p***
*L** Sclera	Age			79.01	<0.0001
	Eyes color			14.30	0.0002
	Dark eyes	112	0.7		
	Light eyes	116	0.7		
*a** Sclera	Age			150.25	<0.0001
	Eyes color			12.67	0.0004
	Dark eyes	135	0.2		
	Light eyes	136	0.1		
*b** Sclera	Age			167.24	<0.0001
	Eyes color			1.93	0.1661
	Dark eyes	134	0.2		
	Light eyes	134	0.1		
*L** Iris	Age			6.12	0.0140
	Eyes color			446.97	<0.0001
	Dark eyes	41	0.7		
	Light eyes	61	0.6		
*a** Iris	Age			7.18	0.0078
	Eyes color			59.63	<0.0001
	Dark eyes	138	0.2		
	Light eyes	132	0.2		
	Age x Eyes color			3.75	0.0539
*b** Iris	Age			0.00	0.9803
	Eyes color			17.09	<0.0001
	Dark eyes	139	0.3		
	Light eyes	135	0.3		
	Age x Eyes color			3.50	0.0624



sclera iris pupil

Figure 1. Labelling of eye regions. Dashed lines show how the eye regions were labeled. Subsequent processing removed the pupil and specular reflections from the iris region.

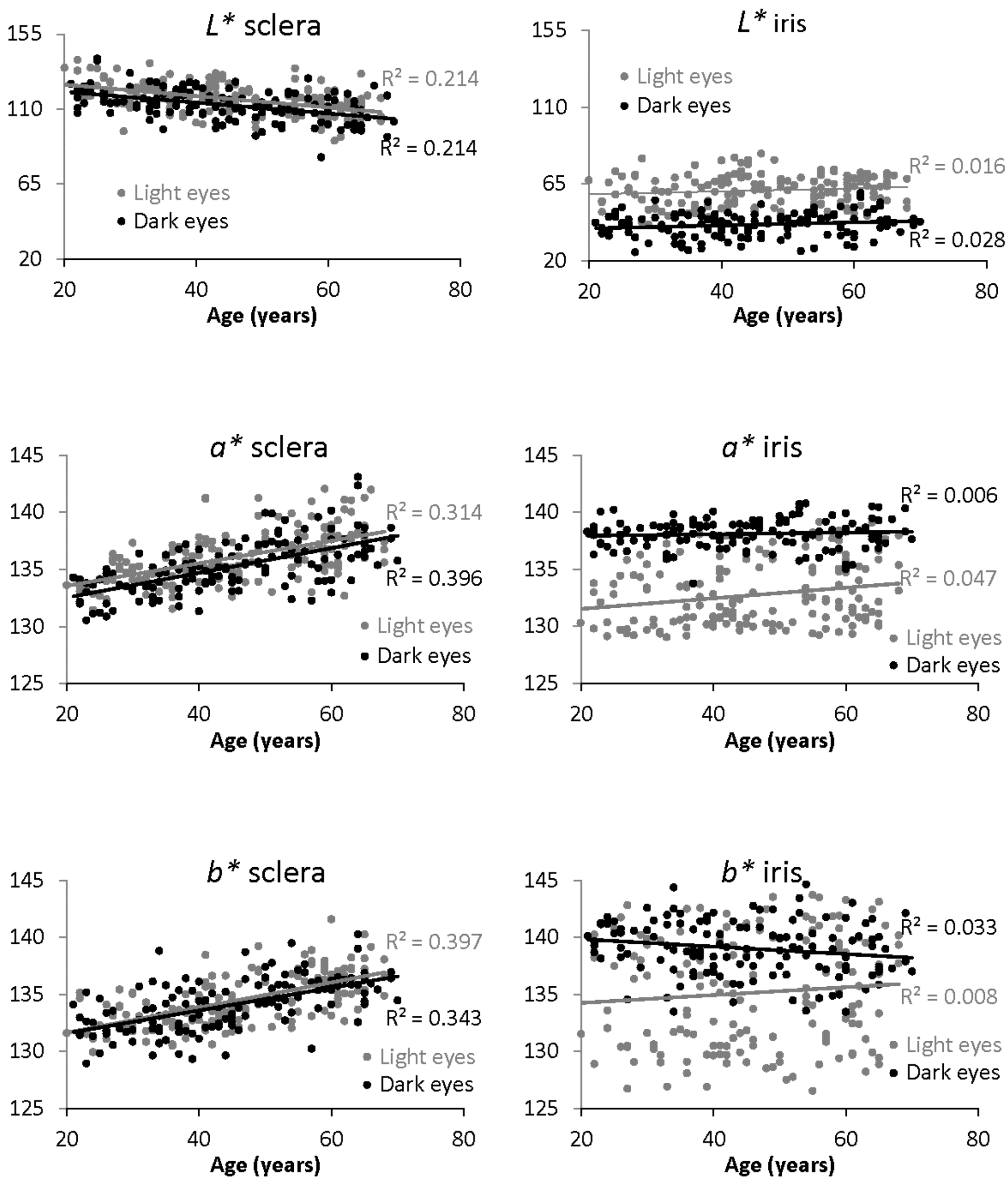


Figure 2: Changes in sclera and iris color with age. The graphs on the left show changes in sclera color with age; the graphs on the right show changes in iris color with age. The top row show the *L** (light-dark) channel, the middle row show *a** (red-green) channel, and the bottom row shows the *b** (yellow-blue) channel.

Figure 3. An example trial from the forced choice task, in the *L**, *a** & *b** condition (i.e. all three color channels have been manipulated). The left image shows a face in which the sclera have been made brighter, greener, and bluer (i.e. the *L** value of the sclera has been increased while the *a** and *b** values have been decreased) and the right image shows a face in which the sclera have been made darker, redder, and yellower (i.e. the *L** value of the sclera has been decreased while the *a** and *b** values have been increased).

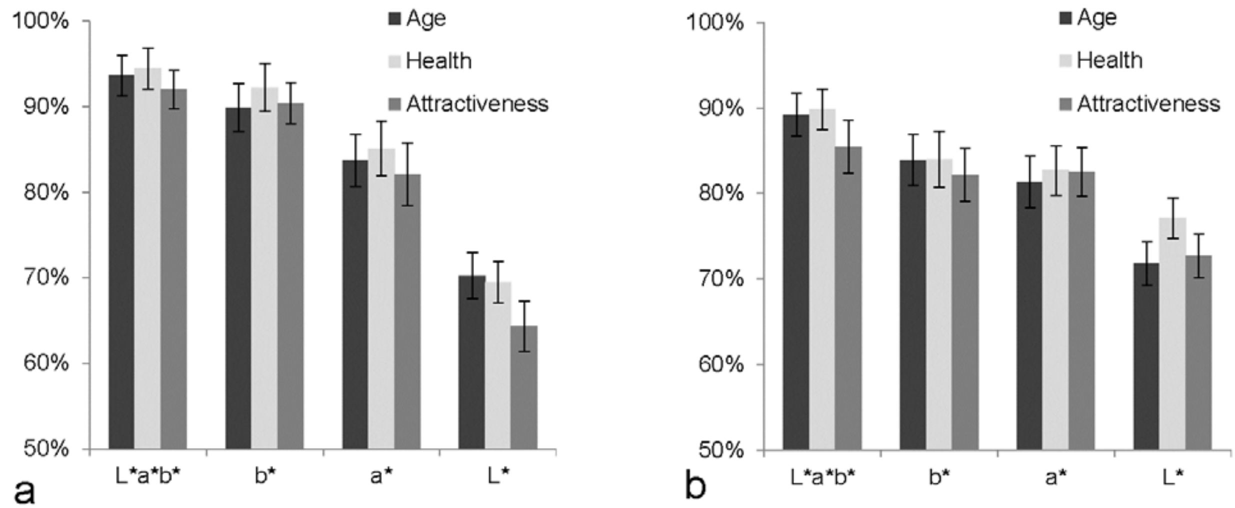


Figure 4. The percentage of trials for which the version of the face judged to be younger, healthier, or more attractive was the one with lighter, greener, or bluer sclera. Chance performance is 50%. Error bars show S.E.M. a) on left shows results from Study 2a with young adult participants. b) on right shows results from Study 2b with middle aged participants.

The following is Supplementary Material for Online Publication.

Table 2. Impact of manipulation of sclera color on the perception of age (Study 2a)

Variables		***Wald χ²***	***P[1]***	***AOR[2]***	***[95% CI][3]***
(A) Color channel	*L**	152.03	<0.0001	1.00	
	*a**	42.49	<0.0001	2.18	[1.72-2.76]
	*b**	91.33	<0.0001	3.80	[2.89-5.00]
	*L*a*b**	138.43	<0.0001	6.27	[4.62-8.52]
(B) Age of the face	Younger faces	1.02	0.6007	1.00	
	Middle aged faces	0.10	0.7577	1.05	[0.76-1.46]
	Older Faces	0.40	0.5251	0.90	[0.65-1.24]
(C) Gender of the raters	Men			1.00	
	Women	17.41	<0.0001	1.63	[1.30-2.04]
A x B (significant interaction)		14.07	0.0289		
*L**	Younger faces			1.00	
	Middle aged faces	2.74	0.0978	1.38	[0.94-2.04]
	Older Faces	1.89	0.1695	0.77	[0.54-1.12]
*a**	Younger faces			1.00	
	Middle aged faces	0.06	0.8098	1.06	[0.68-1.65]
	Older Faces	2.40	0.1215	1.45	[0.91-2.32]
*b**	Younger faces			1.00	
	Middle aged faces	1.70	0.1918	0.68	[0.38-1.21]
	Older Faces	1.06	0.3026	0.74	[0.41-1.32]
*L*a*b**	Younger faces			1.00	
	Middle aged faces	0.31	0.5781	1.23	[0.59-2.55]
	Older Faces	0.46	0.4997	0.80	[0.41-1.54]
Younger faces	*L**			1.00	
	*a**	11.08	0.0009	1.94	[1.31-2.86]
	*b**	39.68	<.0001	4.89	[2.99-8.02]
	*L*a*b**	48.34	<.0001	6.47	[3.82-10.95]
Middle aged faces	*L**			1.00	
	*a**	3.32	0.0684	1.48	[0.97-2.25]
	*b**	12.99	0.0003	2.41	[1.49-3.89]
	*L*a*b**	34.71	<.0001	5.74	[3.21-10.27]
Older faces	*L**			1.00	
	*a**	38.23	<.0001	3.63	[2.41-5.47]
	*b**	44.23	<.0001	4.65	[2.96-7.32]
	*L*a*b**	58.96	<.0001	6.65	[4.10-10.78]

[1] P value of Wald test, [2] Odds Ratios are adjusted on all variables, [3] 95% confidence interval.

Table 3. Impact of manipulation of sclera color on attractiveness perception (Study 2a)

Variables		***Wald χ²***	***P[1]***	***AOR[2]***	***[95% CI][3]***
(A) Color channel	*L**	197.08	<.0001	1.00	
	*a**	65.05	<.0001	2.59	[2.05- 3.26]
	*b**	138.59	<.0001	5.33	[4.03- 7.04]
	*L*a*b**	176.43	<.0001	6.54	[4.96- 8.63]
(B) Age of the face	Younger faces	0.54	0.7632	1.00	
	Middle aged faces	0.32	0.5743	0.92	[0.69- 1.23]
	Older Faces	0.46	0.4969	0.90	[0.67- 1.21]
(C) Gender of the raters	Men			1.00	
	Women	15.30	<.0001	1.54	[1.24-1.91]
A x B (significant interaction)		18.63	0.0048		
*L**	Younger faces			1.00	
	Middle aged faces	0.03	0.8538	1.03	[0.72-1.49]
	Older Faces	5.80	0.0160	0.65	[0.46-0.92]
*a**	Younger faces			1.00	
	Middle aged faces	0.94	0.3312	1.24	[0.81-1.89]
	Older Faces	5.02	0.0250	1.68	[1.07-2.63]
*b**	Younger faces			1.00	
	Middle aged faces	2.00	0.1574	0.67	[0.38-1.17]
	Older Faces	0.02	0.8755	1.05	[0.57-1.93]
*L*a*b**	Younger faces			1.00	
	Middle aged faces	0.26	0.6096	0.84	[0.43-1.64]
	Older Faces	2.90	0.0886	0.58	[0.31-1.09]
Younger faces	*L**			1.00	
	*a**	8.38	0.0038	1.78	[1.20-2.62]
	*b**	41.89	<.0001	5.25	[3.18-8.67]
	*L*a*b**	49.74	<.0001	7.28	[4.19-12.64]
Middle aged faces	*L**			1.00	
	*a**	12.86	0.0003	2.12	[1.41-3.20]
	*b**	31.03	<.0001	3.39	[2.20-5.20]
	*L*a*b**	52.97	<.0001	5.91	[3.66-9.53]
Older faces	*L**			1.00	
	*a**	55.50	<.0001	4.59	[3.07-6.85]
	*b**	66.39	<.0001	8.50	[5.08-14.21]
	*L*a*b**	85.89	<.0001	6.51	[4.38-9.67]

[1] P value of Wald test, [2] Odds Ratios are adjusted on all variables, [3] 95% confidence interval.

Table 4. Impact of manipulation of sclera color on health perception (Study 2a)

Variables		*Wald χ²*	*P*[1]	*AOR*[2]	*[95% CI]*[3]
(A) Color channel	*L**	178.85	<0.0001	1.00	
	*a**	53.84	<0.0001	2.65	[2.04-3.44]
	*b**	108.39	<0.0001	5.86	[4.20-8.17]
	*L*a*b**	119.35	<0.0001	9.98	[6.61-15.09]
(B) Age of the face	Younger faces	1.19	0.5502	1.00	
	Middle aged faces	0.02	0.8887	1.03	[0.72-1.45]
	Older Faces	0.72	0.3970	0.86	[0.61-1.22]
(C) Gender of the raters	Men			1.00	
	Women	31.27	<0.0001	2.33	[1.73-3.14]
A x B (significant interaction)		14.09	0.0286		
*L**	Younger faces			1.00	
	Middle aged faces	1.32	0.2510	1.25	[0.86-1.82]
	Older Faces	1.42	0.2330	0.80	[0.56-1.15]
*a**	Younger faces			1.00	
	Middle aged faces	1.97	0.1604	1.39	[0.88-2.22]
	Older Faces	4.13	0.0420	1.64	[1.02-2.66]
*b**	Younger faces			1.00	
	Middle aged faces	0.12	0.7334	1.12	[0.58-2.17]
	Older Faces	0.61	0.4340	0.78	[0.42-1.45]
*L*a*b**	Younger faces			1.00	
	Middle aged faces	1.93	0.1650	0.57	[0.25-1.26]
	Older Faces	2.43	0.1193	0.53	[0.24-1.18]
Younger faces	*L**			1.00	
	*a**	11.24	0.0008	2.01	[1.34-3.03]
	*b**	44.30	<.0001	6.12	[3.59-10.44]
	*L*a*b**	62.34	<.0001	14.90	[7.62-29.14]
Middle aged faces	*L**			1.00	
	*a**	11.91	0.0006	2.25	[1.42-3.57]
	*b**	35.66	<.0001	5.51	[3.15-9.65]
	*L*a*b**	36.00	<.0001	6.77	[3.62-12.64]
Older faces	*L**			1.00	
	*a**	36.80	<.0001	4.12	[2.61-6.50]
	*b**	40.41	<.0001	5.95	[3.43-10.32]
	*L*a*b**	55.16	<.0001	9.87	[5.39-18.05]
A x C (significant interaction)		15.57	0.0014		
*L**	Men			1.00	
	Women	1.13	0.2888	1.18	[0.87-1.59]
*a**	Men			1.00	
	Women	11.38	0.0007	2.01	[1.34-3.02]
*b**	Men			1.00	
	Women	11.57	0.0007	2.70	[1.52-4.79]
*L*a*b**	Men			1.00	
	Women	15.05	0.0001	4.63	[2.14-10.05]
Men	*L**			1.00	
	*a**	18.36	<.0001	2.03	[1.47-2.80]
	*b**	49.15	<.0001	3.86	[2.65-5.64]
	*L*a*b**	65.59	<.0001	5.03	[3.40-7.44]
Women	*L**			1.00	
	*a**	36.01	<.0001	3.46	[2.31-5.20]
	*b**	60.53	<.0001	8.87	[5.12-15.38]
	*L*a*b**	64.19	<.0001	19.81	[9.54-41.13]

[1] P value of Wald test, [2] Odds Ratios are adjusted on all variables, [3] 95% confidence interval.

Table 5. Impact of manipulation of sclera color on the perception of age (Study 2b)

Variables		*Wald χ²*	*P*[1]	*AOR*[2]	*[95% CI]*[3]
(A) Color channel	*L**	136.74	<.0001	1.00	
	*a**	27.48	<.0001	1.69	[1.39-2.06]
	*b**	54.21	<.0001	2.08	[1.71-2.53]
	*L*a*b**	130.65	<.0001	3.24	[2.65-3.96]
(B) Age of the face	Younger faces	0.13	0.9353	1.00	
	Middle aged faces	0.13	0.7194	0.96	[0.78-1.19]
	Older Faces	0.01	0.9058	0.99	[0.80-1.22]
(C) Gender of the raters	Men			1.00	
	Women	9.94	0.0016	1.35	[1.13-1.62]
A x C (significant interaction)		12.45	0.0060	1.00	
*L**	Men			1.00	
	Women	3.75	0.0528	1.29	[1.00-1.66]
*a**	Men			1.00	
	Women	19.39	<.0001	1.93	[1.44-2.59]
*b**	Men			1.00	
	Women	0.08	0.7728	1.05	[0.77-1.43]
*L*a*b**	Men			1.00	
	Women	1.75	0.1853	1.28	[0.89-1.85]
Men	*L**			1.00	
	*a**	4.89	0.0271	1.38	[1.04-1.83]
	*b**	30.40	<.0001	2.31	[1.71-3.11]
	*L*a*b**	56.07	<.0001	3.24	[2.38-4.41]
Women	*L**			1.00	
	*a**	28.00	<.0001	2.07	[1.58-2.71]
	*b**	23.83	<.0001	1.88	[1.46-2.42]
	*L*a*b**	78.36	<.0001	3.23	[2.49-4.19]

[1] P value of Wald test, [2] Odds Ratios are adjusted on all variables, [3] 95% confidence interval.

Table 6. Impact of manipulation of sclera color on attractiveness perception (Study 2b)

Variables		***Wald χ^2***	***P*[1]**	***AOR*[2]**	***[95% CI]*[3]**
(A) Color channel	*L**	70.74	<.0001	1.00	
	*a**	34.83	<.0001	1.80	[1.48-2.19]
	*b**	30.21	<.0001	1.72	[1.42-2.09]
	*L*a*b**	71.73	<.0001	2.15	[1.80-2.57]
(B) Age of the face	Younger faces	1.04	0.5942	1.00	
	Middle aged faces	0.02	0.8826	1.02	[0.82-1.27]
	Older Faces	0.89	0.3467	1.11	[0.89-1.39]
(C) Gender of the raters	Men			1.00	
	Women	1.87	0.1718	1.14	[0.95-1.37]
A x B (significant interaction)		12.72	0.0477		
*L**	Younger faces			1.00	
	Middle aged faces	0.53	0.4647	0.89	[0.65-1.22]
	Older Faces	4.87	0.0273	0.70	[0.52-0.96]
*a**	Younger faces			1.00	
	Middle aged faces	0.00	1.0000	1.00	[0.70-1.42]
	Older Faces	2.89	0.0891	1.38	[0.95-2.01]
*b**	Younger faces			1.00	
	Middle aged faces	0.07	0.7852	1.05	[0.74-1.50]
	Older Faces	1.04	0.3079	1.21	[0.84-1.74]
*L*a*b**	Younger faces			1.00	
	Middle aged faces	0.47	0.4919	1.15	[0.78-1.69]
	Older Faces	1.70	0.1920	1.30	[0.88-1.93]
Younger faces	*L**			1.00	
	*a**	3.54	0.0597	1.38	[0.99-1.94]
	*b**	3.53	0.0603	1.36	[0.99-1.88]
	*L*a*b**	11.01	0.0009	1.61	[1.22-2.13]
Middle aged faces	*L**			1.00	
	*a**	6.66	0.0099	1.56	[1.11-2.18]
	*b**	7.81	0.0052	1.61	[1.15-2.25]
	*L*a*b**	20.99	<.0001	2.08	[1.52-2.84]
Older faces	*L**			1.00	
	*a**	34.25	<.0001	2.71	[1.94-3.79]
	*b**	22.97	<.0001	2.34	[1.65-3.31]
	*L*a*b**	43.02	<.0001	2.97	[2.15-4.12]
A x C (significant interaction)		7.86	0.0490		
*L**	Men			1.00	
	Women	0.14	0.7107	1.05	[0.81-1.36]
*a**	Men			1.00	
	Women	0.22	0.6412	0.93	[0.68-1.26]
*b**	Men			1.00	
	Women	0.27	0.6005	1.08	[0.80-1.46]
*L*a*b**	Men			1.00	
	Women	7.98	0.0047	1.59	[1.15-2.20]
Men	*L**			1.00	
	*a**	18.38	<.0001	1.91	[1.42-2.57]
	*b**	12.55	0.0004	1.70	[1.27-2.27]
	*L*a*b**	18.64	<.0001	1.75	[1.36-2.25]
Women	*L**			1.00	
	*a**	16.64	<.0001	1.69	[1.32-2.18]
	*b**	18.53	<.0001	1.75	[1.36-2.26]
	*L*a*b**	59.63	<.0001	2.65	[2.07-3.39]

[1] P value of Wald test, [2] Odds Ratios are adjusted on all variables, [3] 95% confidence interval.

Table 7. Impact of manipulation of sclera color on health perception (Study 2b)

Variables		***Wald*** χ^2	***P***[1]	***AOR***[2]	***[95% CI]***[3]
(A) Color channel	*L**	87.06	<.0001	1.00	
	*a**	11.48	0.0007	1.42	[1.16-1.74]
	*b**	19.08	<.0001	1.56	[1.28-1.91]
	*L*a*b**	77.66	<.0001	2.63	[2.12-3.26]
(B) Age of the face	Younger faces	5.29	0.0711	1.00	
	Middle aged faces	2.35	0.1252	1.19	[0.95-1.48]
	Older Faces	5.24	0.0221	1.28	[1.04-1.59]
(C) Gender of the raters	Men			1.00	
	Women	0.23	0.6303	1.05	[0.87-1.26]

[1] P value of Wald test, [2] Odds Ratios are adjusted on all variables, [3] 95% confidence interval.