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Why Do Limbal Rings Cause Faces to Appear Healthier and More Attractive? Resolving Theoretical and Methodological Tensions in Current Research on Perceptions of Faces With(Out) Limbal Rings

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Studies have repeatedly shown that people perceive faces with limbal rings to be healthier and more attractive. Despite consistent support, certain tensions are evident in the current literature on perceptions of faces with(out) limbal rings. Perhaps most notably, the mechanism(s) that cause differences in perceptions of faces with and without limbal rings remains relatively untested, and almost all studies on limbal rings have used the same set of target stimuli. These two tensions draw into question whether this effect is a reliable and valid phenomenon, undercutting the importance of extant research. To resolve these tensions, the current article reports four studies to test the two predominant justifications for differences in perceptions of faces with(out) limbal rings. These four studies support that, while limbal rings themselves may be indicators of health, they do not directly influence perceptions of health and attractiveness. Instead, the contrast of limbal rings with the sclera causes them to appear lighter, which influences perceptions of health and attractiveness as white sclerae are a known indicator of health. These studies also utilize a new set of target stimuli selected and created via defined procedures with a large public face database, enabling future researchers to both use the present stimuli in their studies and apply our procedures to create new stimuli from this database. Together, the efforts of the current study resolve these two primary tensions in the current literature and support that differences in perceptions of faces with(out) limbal rings are a reliable and valid phenomenon.

Public Significance Statement
People perceive faces with limbal rings to be healthier and more attractive, but the reason is still unclear in the literature. We support that limbal rings cause the surrounding sclera to appear lighter, thereby causing people to appear healthier and potentially more attractive. We also provide new tools to study limbal rings in future research.

Keywords: limbal rings, facial perceptions, social perceptions, perceived health, perceived attractiveness

Limbal rings are darkened bands of pigment that span the perimeter of the iris, arising as a manifestation of the corneal limbus where the sclera meets the cornea (Coroneo et al., 2023; Shyu & Wyatt, 2009). Studies have repeatedly shown that people perceive faces with limbal rings to be healthier and more attractive (Brown et al., 2019; Ilicic et al., 2016; Peshek et al., 2011; Sacco et al., 2019).

Catherine Salmon served as action editor.

The author has no conflicts of interest to declare. The data that support the findings of this study are openly available in the Open Science Framework (OSF.io) at https://osf.io/5svmn/?view_only=d764ad1df78446da85a5fa0d915c5ed7, which is discussed in Section C in the additional online materials. All procedures for the current study were approved by the Institutional Review Board of the University of South Alabama. Written informed consent was not obtained for the current studies to maximize anonymity and confidentiality, as written signatures would be the only identifying information linking participants to the study if obtained. Instead, participants were provided an information sheet at the beginning of the studies and asked if they agreed to participate by clicking a button.

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These studies have also shown that women with greater short-term mating preferences are more susceptible to limbal rings, perhaps because they are more receptive to the fitness and health cues of others (Brown & Sacco, 2018; Brown et al., 2019, 2020; Sacco et al., 2019). From these replicable findings, researchers have provided sizable support that limbal rings significantly influence facial perceptions, which poses important implications for the study of evolutionary psychology. Namely, facial perceptions are among the strongest determinants of interpersonal attraction, and no other feature of the face receives greater attention than the eyes (Althoff & Cohen, 1999; Davies & Hoffman, 2002; Peshek et al., 2011). Understanding perceptions of eyes—and influences on these perceptions—produces valuable insights into mate selection and who exhibits stronger reproductive fitness.

Despite these advancements, certain theoretical tensions are evident in the current literature on limbal rings. Perhaps most notably, researchers have argued that this effect occurs because limbal rings cause the surrounding sclera to appear lighter (Brown & Sacco, 2018; Ilicic et al., 2016; Peshek et al., 2011; Sacco et al., 2019), but only indirect evidence has been provided for this justification. Extant findings support that limbal rings are associated with perceived health and attractiveness, but these studies do not provide direct evidence for the cause of these associations. Differences in perceptions of faces with(out) limbal rings may occur because of subconscious perceptions of the surrounding sclera; however, these perceptual differences may instead occur because of limbal rings themselves, as limbal rings are also associated with perceptions of health independent of sclerae. Limbal rings fade in older age, potentially causing them to be direct indicators of health and reproductive fitness (Coroneo et al., 2023; Shyu & Wyatt, 2009). Likewise, gaze detection has been argued to be an important evolutionary advantage of humans, as it allows people to more quickly identify potential threats observed by others in the environment (Emery, 2000; Kobayashi & Hashiya, 2011). As it is easier to detect the gaze of eyes with limbal rings (Perea-García et al., 2021; Peshek et al., 2011), people may prefer eyes with limbal rings for adaptive advantages. The lack of evidence and these alternative justifications produce uncertainty about the cause of the differences in perceptions—and perhaps even their occurrence altogether. Without reliable evidence for the cause of these perceptional differences, it could be argued that they cannot be considered a reliable or valid phenomenon.

In the current article, we report four studies to resolve this tension in the literature. In Studies 1 and 2, we test whether faces with limbal rings are rated as healthier and more attractive than faces without limbal rings but no more than faces with lightened sclerae (and without limbal rings). If differences in perceptions are caused by perceptions of sclerae, faces with limbal rings should produce similar outcomes to faces with lightened sclerae. In Study 3, we test whether irises with limbal rings are rated equally healthy and attractive as irises without limbal rings when all other portions of the face are removed. If perceptual differences are caused by perceptions of the sclera, these differences should not occur when sclerae are removed. Finally, Study 4 addresses an alternative explanation for our findings by applying the most widely used stimuli to study limbal rings (Peshek et al., 2011) while using our sampling frame and source, which provides evidence that our results did not arise because of our chosen participant population.

By conducting these investigations, the current article assesses whether the differences in perceptions of faces with(out) limbal rings are because of perceived lightening of the sclera, which provides several implications for modern theory. Notably, we provide further evidence that these perceptual differences are a replicable phenomenon with explainable mechanisms. This contribution enables future researchers to study this phenomenon with more confidence in the validity of their results, and it further solidifies these perceptual differences as a key mechanism necessary to understand the broader dynamics of facial and fitness perceptions. Our studies also support which mechanisms cause limbal rings to influence facial perceptions. Supporting that faces with limbal rings are perceived more favorably because of perceptions of the lightened sclera can reinforce prior findings produced under this assumption, but identifying alternative mechanisms, such as perceptions of limbal rings themselves, may suggest that research on these differences needs to be redirected to account for these mechanisms. With either finding, the current article uncovers several research directions necessary to understand limbal ring and facial perceptions more broadly, such as the study of faces and irises with differing characteristics. Finally, the current article also

reports the development of new limbal ring stimuli, providing methodological benefits by enabling researchers to move beyond almost sole reliance on a single set of stimuli (Peshek et al., 2011) in addition to other methodological benefits discussed further below.

Background

Faces communicate several pieces of valuable information believed to aid in the survival of early humans. Emotional expressions can indicate to others when dangers may be present in the environment and they should stay alert (e.g., fear), enabling humans to detect potential threats before they have even observed the threats themselves (Keltner et al., 2013; Nesse & Ellsworth, 2009). Expressions can also indicate when an area is believed to be safe (e.g., happiness), allowing humans to relax and conserve energy (Keltner et al., 2013; Nesse & Ellsworth, 2009). Likewise, static characteristics of faces can similarly communicate information beneficial for survival, particularly cues associated with health. For instance, the overall luminance of faces is known to be associated with general health, as even cartoons often represent ill people as being discolored (e.g., green) (Jones et al., 2016; Russell et al., 2016). Communicating illness to kin could indicate when aid is needed, but it could also indicate to unrelated others when to avoid potential infection. These demonstrations of health are also associated with reproductive fitness (Bouchard et al., 1990; Lambert, 2009; Stearns & Ebert, 2001). Identifying whether others are healthy based on their appearance enabled humans to choose mates to maximize their offspring's likelihood of survival. In turn, humans have the tendency to choose mates that appear healthier, and people with physical cues indicative of health are perceived to be more attractive (Kalick et al., 1998; Nedelec & Beaver, 2014; Weeden & Sabini, 2005). Because of the importance of the face for exhibiting information beneficial for survival, people pay a great deal of attention to faces when interacting with others.

Of the face, no other feature receives more attention than the eyes (Althoff & Cohen, 1999; Davies & Hoffman, 2002; Peshek et al., 2011), perhaps because the eyes alone can indicate each piece of information discussed with the face above. Eyelids can indicate emotions, such as retracted eyelids revealing most of the eye as an indicator of surprise (Eisenbarth & Alpers, 2011; Yuki et al., 2007). The sclera of the eye communicates health (Provine et al., 2013; Russell et al., 2014). Sclerae become discolored in old age and from certain illnesses (e.g., cirrhosis). White sclerae indicate good health, whereas darkened or discolored sclerae indicate poorer health. Irises indicate gaze direction. Knowing where a person is looking can allow the quicker identification of potential threats in the environment (Adams et al., 2003; Hoehl & Striano, 2008). Due to the rich communicative nature of eyes, eye contact is seen as paramount for mate selection in humans, and self-help books on dating often recommend maintaining eye contact to create and maintain positive impressions (Croes et al., 2020; Riggio & Woll, 1984). Allowing others to (whether consciously or subconsciously) inspect the eyes can demonstrate health, reproductive fitness, and confidence in social standing. Together, the eye attracts attention from others because of its communicative capabilities, causing each feature of the eye to pose potentially important ramifications for understanding social interactions—especially those involving interpersonal assessments and mate selection.

Perceptions of Limbal Rings

Limbal rings, the focus of the current article, are a particularly important feature of the eye for interpersonal perception. Researchers have frequently supported the differences in perceptions of faces with(out) limbal rings, which is the replicable phenomenon that faces with limbal rings are perceived as healthier and more attractive than those without limbal rings (Brown & Sacco, 2018; Brown et al., 2019, 2020; Ilicic et al., 2016; Peshek et al., 2011; Sacco et al., 2019). These researchers often argue that the darkness of limbal rings produces a stark contrast with the whiteness of the sclera, in turn making them appear lighter. As white sclerae are indicators of youth and good health (Provine et al., 2013; Russell et al., 2014), this contrast is believed to be the mechanism that causes faces with limbal rings to be perceived as healthier. In turn, the fitness associated with healthier faces is believed to also cause them to be perceived as more attractive (Kalick et al., 1998; Nedelec & Beaver, 2014; Weeden & Sabini, 2005). At the same time, extant research has not directly tested whether the contrast between limbal rings and sclerae is indeed the mechanism that produces the differences in perceptions of faces with(out)

limbal rings, which may also be explained by alternative justifications.

Limbal rings themselves are indicators of health. Limbal rings fade in old age and with certain diseases (Coroneo et al., 2023; Shyu & Wyatt, 2009), similar to the sclera. For instance, corneal arcus is the development of lipid deposits around the perimeter of the iris often because of high cholesterol and heart conditions (Ang et al., 2011; Fernández et al., 2007). When corneal arcus occurs, the lipid deposits appear as a lightened band on the edge of the iris, and the limbal ring becomes much less apparent. Faces with darker limbal rings can be indicative of good health, whereas faces without limbal rings can be indicative of poorer health. For these reasons, people may perceive faces with limbal rings as healthier because of the limbal rings themselves (independent of sclerae), potentially causing these faces to also be perceived as more attractive.

Also, limbal rings aid the evolutionary advantage of gaze detection, as it is easier to identify the gaze of eyes with limbal rings (Perea-García et al., 2021; Peshek et al., 2011). The survival of early humans may have benefited from limbal rings, as living in families and producing offspring with limbal rings would enable the detection of environmental threats to be communicated more easily. Independent of associations with health, people may prefer faces with limbal rings because of the evolutionary advantage of easier gaze detection, resulting in faces with limbal rings being perceived as having greater reproductive fitness and attractiveness.

While prior studies have repeatedly supported the differences in perceptions of faces with(out) limbal rings, only indirect evidence has been provided for the mechanism(s) underlying this phenomenon. Researchers have shown that many constructs associated with short-term mating preferences increase the magnitude of the differing perceptions (Brown & Sacco, 2018; Peshek et al., 2011; Sacco et al., 2019). The theoretical justification for these effects is that those with greater short-term mating motivations are more sensitive to indicators of health, and they should more readily perceive these indicators of health and find them more attractive. These researchers assumed that the contrast between limbal rings and sclerae was the triggering health cue; however, limbal rings themselves may have been the triggering health cue because of their associations with fitness, and attributing prior results to the perceived lightening of the sclera may be a misleading assumption. Instead, the relation between the limbal rings and short-term mating preferences could be because of limbal rings independent of their contrast with the sclera.

Because these alternative explanations cannot be ruled out with extant findings, prior theoretical justifications for differences in limbal ring perceptions cannot be considered reliable or valid. This conceptual uncertainty casts significant doubt upon the occurrence of perceptual differences in faces with(-out) limbal rings, undercutting the importance of this ongoing research domain. Likewise, without identifying mechanism(s), the appropriate theoretical perspective to understand the occurrence and implications of the limbal ring perceptions cannot be decisively identified, potentially producing a barrier to identifying the best avenues for future research directions. Therefore, notable implications for research could be provided by resolving this tension in the current literature and providing evidence for the mechanism(s) causing the differences in perceptions of faces with(out) limbal rings. In the current article, we develop a set of hypotheses and studies to assess whether these perceptual differences are caused by the perceived lightening of the sclera or limbal rings themselves.

Hypothesis Development

To determine the mechanism of the differences in perceptions of faces with(out) limbal rings, we propose a series of hypotheses that involve comparisons between faces without limbal rings, faces with limbal rings, and faces with lightened sclerae. Regardless of the underlying mechanism(s) for limbal ring perceptions, faces with limbal rings and faces with lightened sclerae should be perceived as healthier and more attractive than faces without limbal rings, as both limbal rings and lightened sclerae are believed to be indicators of fitness. If the differing perceptions are because of perceptions of lightened sclerae, then it would be expected that faces with limbal rings and faces with lightened sclerae would be perceived as similarly healthy and attractive, as they would incur the same mechanisms that influence the perceptions. In other words, if the differences in perceptions of faces with(out) limbal rings align with prior assertions, then it is expected that faces with limbal rings will be rated as healthier and more attractive than faces without limbal rings but no more than faces with lightened sclerae.

At the same time, limbal rings may produce effects of their own in addition to their influence on perceptions of the surrounding sclera, as they could both be perceived as direct indicators of health and produce a contrast with the surrounding sclera that causes it to be perceived as lighter. If the case, then faces with limbal rings would be perceived as healthier and more attractive than faces with lightened sclerae, as faces with limbal rings would produce effects from both limbal rings themselves and the contrast with sclerae whereas faces with lightened sclerae would only produce effects via the latter mechanism. Therefore, if limbal rings also produce an effect of their own, then faces with limbal rings are expected to be perceived as healthier and more attractive than faces with lightened sclerae, and both would still be expected to be perceived as healthier and more attractive than faces without limbal rings.

By testing these competing proposals, we determine whether differences in perceptions of faces with(out) limbal rings are because of the contrast of limbal rings with the sclera or because of independent effects of their own. Our hypotheses presented below provide evidence for the former proposal (contrast with sclerae) if supported and provide evidence for the latter proposal (limbal rings themselves) if not supported.

Hypothesis 1 (H1): Compared to faces without limbal rings, participants perceive faces with limbal rings as (a) healthier and (b) more attractive.

Hypothesis 2 (H2): Compared to faces with regular sclerae, participants perceive faces with lightened sclerae as (a) healthier and (b) more attractive.

Hypothesis 3 (H3): Participants do not perceive a difference between faces with limbal rings (and regular sclerae) compared to faces with lightened sclerae (and without limbal rings) regarding their (a) health and (b) attractiveness.

Methodological Objectives

Methodological tensions are also evident in research on limbal rings. Almost all extant studies have utilized a set of 40 pictures created by Peshek et al. (2011), which includes a set of 20 faces with and without limbal rings (Brown & Sacco, 2018; Brown et al., 2019, 2020; Sacco et al., 2019). While these pictures may be suitable for studying the limbal rings, the reliance on a single set of target stimuli poses concerns for the validity and generalizability of the research. First, as with any study materials, it is possible that unintentional aspects of these photos caused prior results rather than the effects of limbal rings themselves. Using varied target stimuli is necessary to address this concern, as replicating effects across differing study designs is necessary to ensure research validity. Second, even if prior results were because of limbal rings, these effects may unknowingly occur only when studying images with common characteristics of the 20 faces, such as faces that are particularly (un)attractive. A systematic process was not described by Peshek et al. (2011) to identify their 20 faces, causing uncertainties regarding the conditions that differences may occur in perceptions of faces with(out) limbal rings. Third, two of the three databases used to generate the 40 pictures are no longer available, causing further difficulties in creating new pictures with and without limbal rings.

To resolve these tensions, we undergo a systematic approach to create a new set of target stimuli. Using a public database of face images with associated normed data, the Chicago Face Database (Ma et al., 2015), we systematically identify 20 images to use as target stimuli from 828 potential images. We choose faces that are perceived as young (age 20–30), white, and moderately attractive based on the normed data. By using a systematic approach, researchers can better understand which aspects of faces have (and have not) been tested with the limbal rings effect, enabling future research to progress in a more directed manner by testing faces with other characteristics. For instance, future researchers could test whether more (un) attractive faces than our target stimuli produce larger differences in perceptions, as its association with short-term mating may suggest that it would be stronger with attractive faces (as discussed further below). Therefore, the use of this extensive database and systematic selection procedures enables future research to investigate new research questions via a more systematic approach.

We also apply a defined approach to create our images without limbal rings, with limbal rings, and with lightened sclerae, which is detailed in Section A in the additional online materials with step-by-step instructions and pictures. In doing so, researchers can apply our approach with other images in the Chicago Face Database (Ma et al., 2015) to test perceptual differences with varied

target stimuli, such as pictures with facial characteristics beyond those tested in the current article. Future researchers could also modify our process based on our instructions to test variations of perceptual differences. For instance, Section A in the additional online materials provides instructions on how to create six-pixel limbal rings for the original photos within the Chicago Face Database (Ma et al., 2015), but our instructions could be easily modified to create thinner (e.g., four pixel) or thicker (e.g., eight pixel) limbal rings and assess whether limbal ring thickness influences its effects. Via our methodological efforts, we provide a flexible approach for future research to test a multitude of characteristics associated with limbal rings and derive novel theoretical insights. By doing so, we provide an avenue for future research to produce methodologically sound investigations into perceptions of faces with limbal rings.

Study 1

In Study 1, we test our hypotheses and report the development of pictures without limbal rings or lightened sclerae, with limbal rings, and with lightened sclerae. As studies have supported that the effects of limbal rings are more pronounced with participants who have greater short-term mating motivations (Brown & Sacco, 2018; Brown et al., 2019, 2020), we restrict participation to women attracted to men between the ages of 18 and 30, and our target pictures solely included those perceived to be between the ages of 18 and 30. Also, races differ regarding the average tint of their sclerae (Blake et al., 2003), suggesting that the eyes of people from different races may be perceived differently. For this reason, we restrict participation to those self-identified as white and our target pictures to those self-identified and perceived to be white to reduce potential heterogeneity in our observed effects. As discussed in our limitations and future directions section, testing the limbal ring perceptions with target stimuli representing different races is a clear and important direction for immediate future research.

Method

The procedures for all three studies were approved by the institutional review board of the primary authors' institution (Protocol 2111527).

Participants

We recruited 128 participants from Prolific, who participated in exchange for $2.00 in U.S. dollars. Prior research has suggested that the effect of limbal rings on perceptions is moderate in strength (Brown & Sacco, 2018; Brown et al., 2019, 2020; Peshek et al., 2011), and an a priori power analysis in G*Power (Faul et al., 2007) suggested that a sample size of at least 109 is necessary to obtain sufficient statistical power ($dz = 0.35$, $\beta = .95$). We required that all participants must be fluent in the English language, between the ages of 18 and 30, self-identify as a woman, have a sexual attraction towards men (e.g., straight, bisexual, pansexual), and self-identify as white. We also removed all participants that failed more than one of three attention checks, resulting in a final sample size of 121 ($age_{\bar{x}} = 24.43$, $age_{SD} = 2.53$; 69% straight, 28% bisexual, and 3% other or unreported; located in: 24% Poland, 21% Portugal, 13% United Kingdom, 12% Italy, and 30% other or unreported). Therefore, our study was sufficiently powered.

Materials

Targets. We created a total of 60 pictures from 20 images within the Chicago Face Database (Ma et al., 2015), which includes images of faces with associated demographic and norming data. To choose the 20 images, we reduced the database to people who self-identified as white, were most often perceived to be white, and were rated to be between the ages of 20 and 30 (from norming data). We obtained images of neutrally expressive effect for the 10 men and 10 women with normed attractiveness ratings closest to the median for the reduced database.

Using Gimp 2.10.6, we first created pictures by removing limbal rings via photoshop techniques to replace the outer eye pigment with the inner eye pigment. We did not replace irises in the original images by covering them with irises from an eye database (e.g., Peshek et al., 2011), as doing so would change eye colors and potentially introduce a confound. We also chose not to enlarge the inner eye to cover the outer eye, as doing so would enlarge the pupal and again potentially introduce a confound. Second, we created the limbal ring pictures by adding a four-pixel black ring around the perimeter of the eyes with an opacity value of 50.0, which was the opacity reported by Peshek et al. (2011). A ring of four pixels was chosen

because it mimicked the created limbal rings of Peshek et al. (2011) and the natural limbal rings of the original images. Third, we created the lighter sclera pictures by adding a white layer overtop the sclera with an opacity value of 12.5. This value was chosen based on pilot testing, as it was perceived to lighten the sclera while appearing natural and only slightly noticeable. Final pictures were reduced to a size of 800 × 562 pixels, as the original size of images in the Chicago Face Database is too large to be easily present on most household monitors. Figures 1 and 2 provide example stimuli for all studies, and all stimuli are included in Section B in the additional online materials.

Ratings. For each picture, participants answered the following items: "Based on their appearance, how healthy would you rate the person in the picture above?" (1 = *extremely unhealthy* to 9 = *extremely healthy*) and "Based on their appearance, how attractive would you rate the person in the picture above?" (1 = *extremely unattractive* to 9 = *extremely attractive*).

Procedure

Participants enrolled in the study via the Prolific platform. They were told that they would be asked to answer two questions for each of 60 pictures and they "may spend as much time as you wish looking at the pictures, but it is usually best to answer based on your initial instinct or feelings." They were then, one at a time, randomly shown each picture, which was programmed to show no version of the same face in consecutive order. Afterward, participants completed demographic items, disclosed the purpose of the study, and provided compensation.

Figure 1
Example of Baseline Stimuli in Studies 1 and 2

Note. Image taken from "The Chicago Face Database: A Free Stimulus Set of Faces and Norming Data," by D. S. Ma, J. Correll, and B. Wittenbrink, 2015, *Behavior Research Methods*, *47*(4), pp. 1122–1135 (https://doi.org/10.3758/s13428-014-0532-5). Copyright 2015 by Springer. Figure presented in same size and resolution to participants in Studies 1 and 2. See the online article for the color version of this figure.

Results

The data set used for Study 1 is provided in Section C in the additional online materials. We conducted 2 (target gender: male vs. female) × 3 (eyes: without limbal rings vs. limbal rings vs. light sclerae) repeated-measures analyses of variance (ANOVAs) for each outcome. Estimated marginal means (EMMs) and standard errors are provided in Table 1.

Perceived Health

A significant main effect for eyes, $F(2, 119) = 3.43$, $p = .04$, $\eta_p^2 = .04$, and no significant interaction between eyes and gender, $F(2, 119) = 0.44$, $p = .65$, $\eta_p^2 = .01$, were observed for the outcome of perceived health. The pooled EMMs of the eye conditions were: without limbal rings (EMM = 5.64, $SE = 0.07$), limbal rings (EMM = 5.67, $SE = 0.07$), and light sclerae (EMM = 5.69, $SE = 0.07$). The simple main effect comparison with a least significant difference adjustment between the without limbal rings and limbal rings conditions ($\Delta = -0.04$, $SE = 0.02$, $p = .11$, 95% CI [−0.08, 0.01]) and the limbal rings and light sclerae conditions ($\Delta = -0.02$, $SE = 0.02$, $p = .38$, 95% CI [−0.06, 0.02]), were not significant, whereas the comparison between the without limbal rings and light sclerae condition was significant ($\Delta = -0.05$, $SE = 0.02$, $p = .01$, 95% CI [−0.10, −0.01]). Because we hypothesized that the limbal ring and light sclera conditions would not differ (rather than differ), we also performed a two one-sided tests (TOST) paired samples equivalence analysis (Lakens et al., 2018). We used a conservative assessment of mean equivalence by testing lower and upper bounds of −0.3 and 0.3 (Hedges' *g*). The tests of both the lower, $t(120) = 15.51$, $p < .01$, and upper bounds, $t(120) = -13.73$, $p < .01$, were statistically significant, supporting the mean equivalence of the limbal ring and light sclera conditions.

Figure 2
Visual Demonstration of Condition Differences in Studies 1, 2, and 3

Example Images	Descriptions
	Example of eyes in baseline stimuli for Studies 1 and 2.
	Example of eyes in limbal ring stimuli for Study 1.
	Example of eyes in light sclera stimuli for Study 1.
	Example of eyes in limbal ring stimuli for Study 2.
	Example of eyes in light sclera stimuli for Study 2.
	Example of eyes in baseline stimuli for Study 3.
	Example of eyes in limbal ring stimuli for Study 3.

Note. Figures presented in the same resolution to participants in Studies 1, 2, and 3 (with full faces shown—see Figure 1). See the online article for the color version of this figure.

Perceived Attractiveness

No significant main effect was observed for eyes, $F(2, 119) = 1.76$, $p = .18$, $\eta_p^2 = .03$, and no significant interaction was observed between eyes and gender, $F(2, 119) = 1.79$, $p = .17$, $\eta_p^2 = .03$, for the outcome of perceived attractiveness. A TOST paired samples analysis again (Hedges' $g = \pm 0.3$) found mean equivalence between the limbal ring and light sclera conditions for the lower, $t(120) = 14.37$, $p < .01$, and upper bounds, $t(120) = -16.88$, $p < .01$.

Discussion

Study 1 did not support the differences in perceptions of faces with(out) limbal rings for either perceived health or attractiveness, and it did not support that lighter sclerae causes participants to perceive faces as more attractive. It did support that participants perceive faces with lighter sclerae as healthier than faces without limbal rings, and they also perceive faces with lighter sclerae as not healthier or attractive than faces with limbal rings. These mixed findings merit

Table 1
Study 1: Estimated Marginal Means and Standard Errors

Outcome	Picture gender	Baseline	Limbal rings	Light sclerae
Perceived health	Male	5.72 (0.08)	5.77 (0.08)	5.78 (0.08)
	Female	5.56 (0.07)	5.58 (0.08)	5.61 (0.07)
Perceived attractiveness	Male	4.32 (0.09)	4.33 (0.09)	4.32 (0.09)
	Female	5.25 (0.08)	5.31 (0.07)	5.26 (0.07)

Note. Estimated marginal means are presented first in each cell, followed by standard errors in parentheses.

further investigation, as they contrast with previously replicated results on differences in perceptions of faces with(out) limbal rings. We suggest that the nonsignificant findings may have arisen because of the target stimuli. That is, the created limbal rings and lightened sclerae may not have been prominent enough in the images, and participants may have rated the pictures similarly because the differences in faces were not consciously or even subconsciously observed.

Study 2

We test this proposal in Study 2 by creating target stimuli with more prominent limbal rings and lightened sclerae, such that greater differences between the pictures may be observed.

Method

Participants

We recruited 129 participants from Prolific, who participated in exchange for $1.90 in U.S. dollars. We imposed the same requirements as Study 1, and participants could not have participated in Study 1. We again removed those who failed more than one attention check, resulting in a final sample size of 119 ($age_{\bar{x}} = 24.16$, $age_{SD} = 2.63$; 64% straight, 33% bisexual, and 3% other; located in: 30% Portugal, 14% Poland, 12% United Kingdom, 9% Italy, and 35% other). Considerations for statistical power were identical to Study 1, indicating that Study 2 was sufficiently powered.

Materials

Targets. We used the same 20 pictures from the Chicago Face Database from Study 1. To create the limbal ring pictures, we added a six-pixel black ring around the perimeter of the eye with an opacity value of 66.0. To create the lighter sclera pictures, we added a white layer overtop the sclerae with an opacity value of 25.0. Based on initial pilot testing, these additions were perceived as appearing natural but more noticeable, especially when compared to the stimuli of Study 1. Detailed descriptions of our process to create these images are provided in Section A in the additional online materials. Figures 1 and 2 provide example stimuli for all studies, and all stimuli are included in Section B in the additional online materials.

Ratings. We used the same two items as Study 1.

Procedure

Participants completed the same procedures as Study 1.

Results

The data set used for Study 2 is provided in Section C in the additional online materials. We conducted 2 (target gender: male vs. female) $\times$ 3 (eyes: without limbal rings vs. limbal rings vs. light sclerae) repeated-measures ANOVAs for each outcome. Table 2 provides EMMs and standard errors.

Perceived Health

A significant main effect for eyes, $F(2, 117) = 14.62$, $p < .01$, $\eta_p^2 = .20$, and no significant interaction between eyes and gender, $F(2, 117) = 2.30$, $p = .11$, $\eta_p^2 = .04$, were observed for perceived health. The pooled EMMs of the eye conditions were: without limbal rings (EMM = 5.63, SE = 0.07), limbal rings (EMM = 5.76, $SE = 0.07$), and light sclerae (EMM = 5.73, $SE = 0.07$). The simple main effect comparison with a least significant difference adjustment between the without limbal rings and limbal rings conditions

Table 2
Study 2: Estimated Marginal Means and Standard Errors

Outcome	Picture gender	Baseline	Limbal rings	Light sclerae
Perceived health	Male	5.65 (0.08)	5.79 (0.07)	5.70 (0.08)
	Female	5.60 (0.08)	5.74 (0.08)	5.75 (0.08)
Perceived attractiveness	Male	4.22 (0.09)	4.24 (0.10)	4.21 (0.09)
	Female	4.97 (0.09)	5.05 (0.09)	5.03 (0.09)

Note. Estimated marginal means are presented first in each cell, followed by standard errors in parentheses.

($\Delta = -0.14$, $SE = 0.03$, $p < .01$, 95% CI [−0.18, −0.09]), and the without limbal rings and light sclerae condition ($\Delta = -0.10$, $SE = 0.03$, $p < .01$, 95% CI [−0.16, −0.04]) were significant, whereas the comparison of the limbal rings and the light sclerae conditions were not significant ($\Delta = 0.04$, $SE = 0.03$, $p = .20$, 95% CI [−0.02, 0.09]). A TOST paired samples analysis (Hedges' $g = \pm 0.3$) found mean equivalence between the limbal ring and light sclera conditions for the lower, $t(118) = 9.09$, $p < .01$, and upper bounds, $t(118) = -11.66$, $p < .01$.

Perceived Attractiveness

No significant main effect was observed for eyes, $F(2, 117) = 2.24$, $p = .11$, $\eta_p^2 = .04$, and no significant interaction was observed between eyes and gender, $F(2, 117) = 1.30$, $p = .28$, $\eta_p^2 = .02$, for the outcome of perceived attractiveness. A TOST paired samples analysis (Hedges' $g = \pm 0.3$) found mean equivalence between the limbal ring and light sclera conditions for the lower, $t(118) = 19.17$, $p < .01$, and upper bounds, $t(118) = -21.25$, $p < .01$.

Discussion

Study 2 did not support that limbal rings or lighter sclerae cause faces to be perceived as more attractive. It did, however, support that faces with limbal rings and faces with lighter sclerae are perceived to be healthier than faces without limbal rings, and faces with limbal rings and faces with lighter sclerae were perceived to be similarly healthy and attractive. These results more strongly align with prior research and our hypotheses, and they more strongly support that differences in perceptions of faces with(out) limbal rings are because of perceptions of sclerae.

Study 3

Thus far, we argued that eyes with limbal rings should produce similar outcomes to eyes with lightened sclerae if the limbal ring perceptions are caused by perceptions of lightened sclerae alone, and eyes with limbal rings should produce stronger outcomes than eyes with lightened sclerae if the perceptual differences are caused by both perceptions of lightened sclerae and limbal rings. Studies 1 and 2 were more supportive of the former argument. Neither study showed that eyes with limbal rings produced stronger effects for any outcome compared to eyes with lightened sclerae, and Study 2 supported that faces with limbal rings and faces with lightened sclerae were both perceived as healthier than faces without limbal rings or lightened sclerae.

Despite these supportive findings, it could be argued that limbal rings impact perceived health and attractiveness without influencing perceptions of the sclera, which coincidentally produces a similar effect to lightening the sclera. For this reason, we report Study 3, which compares the effect of irises with limbal rings to irises without limbal rings when all other aspects of the face are removed (including the sclerae). If the two produce similar effects, then the perceptual differences can be further supported to be caused by perceptions of lighter sclerae, as the differences would not occur when the sclerae are not present. If irises with limbal rings still produce stronger effects, then the perceptual differences can be supported to be caused by limbal rings themselves, as the perceptual differences would still occur when the sclerae are not present.

> *Hypothesis 4* (*H4*): When all other aspects of the face are removed, participants do not perceive a difference between irises with limbal rings and irises without limbal rings regarding their (a) health and (b) attractiveness.

Method

Participants

We recruited 127 participants from Prolific, who participated for $1.20 in U.S. dollars. We imposed the same requirements as Studies 1 and 2, and participants could not have participated in Study 1 or 2. We removed those who failed more than one attention check, resulting in a sample size of 121 ($age_{\bar{x}} = 24.81$, $age_{SD} = 2.79$; 60% straight, 38% bisexual, and 2% other; located in: 30% United Kingdom, 22% Portugal, 14% Poland, 9% Italy, and 25% other). Statistical power considerations were more lenient than Study 1 or 2, indicating that Study 3 was sufficiently powered.

Materials

Targets. We utilized the same 20 pictures of the Chicago Face Database from Studies 1 and 2. The faces without limbal rings used in Studies 1 and 2 were used to create photos without limbal rings, and faces with limbal rings used in Study 2 were used to create limbal ring photos.

All aspects of the photos were removed other than the irises, which included removing the sclerae. Figures 1 and 2 provide example stimuli for all studies, and all stimuli are included in Section B in the additional online materials.

Ratings. We used the same two items as Studies 1 and 2, but participants responded regarding the "eye in the picture above." We chose the word "eye" instead of "iris" because it was determined to be more understandable to the average participant.

Procedure

Participants completed the same procedures as Studies 1 and 2.

Results

The data set used for Study 3 is provided in Section C in the additional online materials. We conducted 2 (target gender: male vs. female) × 2 (eyes: without limbal rings vs. limbal rings) repeated-measures ANOVAs for each outcome. EMMs and standard errors are provided in Table 3.

Perceived Health

No significant main effect for eyes, $F(1, 120) = 1.09$, $p = .30$, $\eta_p^2 = .01$, and no significant interaction between eyes and gender, $F(1, 120) = 0.18$, $p = .67$, $\eta_p^2 = .00$, were observed for perceived health. A TOST paired samples analysis (Hedges' $g = \pm 0.3$) found mean equivalence between the without limbal rings and limbal ring conditions for the lower, $t(120) = 11.15$, $p < .01$, and upper bounds, $t(120) = -9.06$, $p < .01$.

Perceived Attractiveness

No significant main effect for eyes, $F(1, 120) = 0.00$, $p = .95$, $\eta_p^2 = .00$, and no significant interaction of eyes and gender, $F(1, 120) = .61$, $p = .44$, $\eta_p^2 = .01$, were observed for perceived attractiveness. A TOST paired samples analysis (Hedges' $g = \pm 0.3$) found mean equivalence between the without limbal rings and limbal ring conditions for the lower, $t(120) = 133.67$, $p < .01$, and upper bounds, $t(120) = -13.78$, $p < .01$.

Discussion

The objective of Study 3 was to determine whether the differences in perceptions of faces with(out) limbal rings occur when sclerae are not present. The results supported that irises with limbal rings were perceived as no more healthy or attractive than irises without limbal rings when sclerae are not present, providing further support that the perceptual differences are indeed because of the perceived lightening of the sclera.

Study 4

The results of Studies 1, 2, and 3 provide significant support for our hypotheses, and the creation of our stimuli (and the procedures to create them) enables more robust assessments of limbal ring perceptions. At the same time, an alternative explanation for our findings could be our use of a different sampling frame and source. We sampled women aged 20–30 across multiple countries, whereas the typical sample in studies of limbal rings are college students (e.g., aged 18–22) from a single university. It could be argued that we observed differences in our results, especially regarding perceived attractiveness, because of our sampling frame and source rather than the substantive effects of our stimuli. For this reason, we conduct a final study.

We replicate our methodology using the stimuli of Peshek et al. (2011), which has been utilized in almost every study of limbal rings. If we obtain results consistent with Studies 1, 2, and 3, then

Table 3
Study 3: Estimated Marginal Means and Standard Errors

Outcome	Picture gender	Baseline	Limbal rings
Perceived health	Male	4.88 (0.09)	4.93 (0.09)
	Female	4.81 (0.09)	4.82 (0.09)
Perceived attractiveness	Male	4.55 (0.11)	4.58 (0.11)
	Female	4.49 (0.11)	4.46 (0.11)

Note. Estimated marginal means are presented first in each cell, followed by standard errors in parentheses.

the observed differences between the present results and prior articles are more likely to have arisen because of our sampling frame and source, as we would continue to find dissimilar results even while using the same stimuli as prior studies. If we obtain results consistent with the prior literature, then the observed differences in Studies 1, 2, and 3 are more likely to have arisen because of our created stimuli, as we would find similar results even while using our sampling frame and source. If this latter possibility is found, then the current article creates an extensive number of directions for future research, as it would suggest that undetected features of the facial stimuli are necessary to observe certain effects regarding limbal rings. As discussed below, researchers could utilize our procedures to develop stimuli with differing characteristics to determine which features are most likely to produce differing results when comparing faces with(out) limbal rings. To assess these proposals, we retest H1 with the stimuli of Peshek et al. (2011).

Method

Participants

We recruited 121 participants from Prolific, who participated for $1.20 in U.S. dollars. We imposed the same requirements as Studies 1, 2, and 3. Participants could not have participated in Studies 1, 2, or 3. We removed those who failed more than one attention check, resulting in a sample size of 119 ($age_{\bar{x}} = 24.17$, $age_{SD} = 2.87$; 65% straight, 32% bisexual, and 4% other; located in: 22% Poland, 18% Portugal, 13% United Kingdom, 8% Italy, and 40% other). Study 4 was sufficiently powered, as it had the same statistical power considerations as Study 3.

Materials

Targets. We utilized the stimuli of Peshek et al. (2011). Like Studies 1, 2, and 3, these stimuli include 10 female faces with limbal rings, 10 female faces without limbal rings, 10 male faces with limbal rings, and 10 male faces with limbal rings. Readers can refer to Peshek et al. (2011) for a description of how these stimuli were created and example images.

Ratings. We used the items from Studies 1 and 2 to assess perceived health and attractiveness.

Procedure

Participants completed the same procedures as Studies 1, 2, and 3.

Results

The data set used for Study 4 is provided in Section C in the additional online materials. We conducted 2 (target gender: male vs. female) $\times$ 2 (eyes: without limbal rings vs. limbal rings) repeated-measures ANOVAs for each outcome. EMMs and standard errors are provided in Table 4.

Perceived Health

A significant main effect for eyes, $F(1, 118) = 34.17$, $p < .01$, $\eta_p^2 = .23$, and a significant interaction between eyes and gender, $F(1, 118) = 14.44$, $p < .01$, $\eta_p^2 = .11$, were observed for perceived health. While the EMMs were similar for female stimuli without (EMM = 6.02, $SE = 0.09$) and with limbal rings (EMM = 6.11, $SE = 0.09$), these figures were notably divergent for male stimuli without (EMM = 5.68, $SE = 0.09$) and with limbal rings (EMM = 6.00, $SE = 0.09$). Because the interaction was significant, we performed a TOST paired samples analysis (Hedges' $g = \pm 0.3$) on the male stimuli, as this was the gender with a larger difference between ratings. This TOST analysis did not find mean equivalence between the without limbal rings and limbal ring

Table 4
Study 4: Estimated Marginal Means and Standard Errors

Outcome	Picture gender	Baseline	Limbal rings
Perceived health	Male	5.68 (0.09)	6.00 (0.09)
	Female	6.02 (0.09)	6.11 (0.09)
Perceived attractiveness	Male	4.94 (0.10)	5.18 (0.10)
	Female	5.48 (0.09)	5.49 (0.09)

Note. Estimated marginal means are presented first in each cell, followed by standard errors in parentheses.

conditions for the upper bound, $t(118) = .53$, $p = .70$.

Perceived Attractiveness

A significant main effect for eyes, $F(1, 118) = 14.76$, $p < .01$, $\eta_p^2 = .00$, and a significant interaction between eyes and gender, $F(1, 118) = 18.46$, $p < .01$, $\eta_p^2 = .14$, were observed for perceived attractiveness. The EMMs were similar for female stimuli without (EMM = 4.58, $SE = 0.09$) and with limbal rings (EMM = 5.49, $SE = 0.09$), but these figures were notably divergent for male stimuli without (EMM = 4.94, $SE = 0.10$) and with limbal rings (EMM = 5.18, $SE = 0.10$). Again, we performed a TOST paired samples analysis (Hedges' $g = \pm 0.3$) on the male facial stimuli, which did not find mean equivalence between the without limbal rings and limbal ring conditions for the upper bound, $t(118) = 1.27$, $p = .10$.

Discussion

Study 4 replicated the results of prior articles while using the stimuli of Peshek et al. (2011) with our sampling frame and source, and a significant interaction was seen between the presence of limbal rings and gender. Specifically, perceptions of female faces did not notably differ with or without the presence of limbal rings, but male faces with limbal rings were perceived to be healthier and more attractive than faces without limbal rings. This finding indicates that the results of Studies 1, 2, and 3 did not arise because of our sampling frame and source, and they instead occurred because of the substantive nature of our stimuli. Differences between the results of our other studies (namely Study 2) and Study 4 also suggest that undetected features of faces notably alter perceptions of faces with and without limbal rings. Exploring this finding is only one of the many potential directions for future research discussed below.

General Discussion

Differences in perceptions of faces with(out) limbal rings have been supported across several studies, and authors have repeatedly argued that its occurrence is because of the perceived lightening of the sclera (Brown et al., 2019, 2020; Peshek et al., 2011; Sacco et al., 2019). To probe this possibility, the two primary theoretical goals of the current article were to first assess whether faces with limbal rings are perceived as healthier and more attractive than faces without limbal rings but no more than faces with lightened sclerae, and to also test whether irises with limbal rings were rated as no more healthy or attractive as irises without limbal rings when all other aspects of the face were removed (e.g., no sclerae). Our primary methodological goal was to test these effects with a new set of stimuli systematically developed from a large database via a process that can be replicated to create additional target stimuli in future research.

Study 1 supported that faces with lightened sclerae but not limbal rings were perceived as healthier than faces without limbal rings, and it did not support that faces with limbal rings or lightened sclerae are perceived as more attractive than faces without limbal rings. Given that the findings of Study 1 notably conflicted with prior research, we developed stimuli with more pronounced limbal rings and lightened sclerae in Study 2. Study 2 supported that faces with limbal rings are perceived as healthier than faces without limbal rings but no more than faces with lightened sclerae, and it again did not support that faces with limbal rings or lightened sclerae are perceived as more attractive than faces without limbal rings. These findings supported that faces with limbal rings produce similar effects to faces with lightened sclerae, lending support that faces with limbal rings are perceived as healthier because of the perceived lightening of the sclera. To rule out the alternative explanation that limbal rings and lightened sclerae independently and coincidentally produce similar effects, Study 3 tested whether irises with limbal rings produce similar findings to irises without limbal rings when all other aspects of the face were removed (including the sclerae), which was supported. Study 3 provided further evidence that the perceptual differences are because of the perceived lightening of the sclera.

We finally performed Study 4 to rule out the alternative explanation that divergences in the results of our studies and prior articles, particularly regarding perceived attractiveness, arose because of our sampling frame and source. That is, our samples consisted of young women aged 20–30 from multiple countries, whereas most prior articles utilize samples of college students mostly aged 18–22 from a single university. For

this reason, we utilized our sampling frame and source but administered the stimuli of Peshek et al. (2011), which have been used in almost all studies on limbal rings. The results of Study 4 were consistent with prior articles, supporting that our findings did not arise because of our sampling frame and source. Instead, differences between the results of Studies 1, 2, and 3 with prior articles are likely because of substantive characteristics of our stimuli. These results provide several notable implications and future research directions.

Implications and Future Research Directions

Explanatory Mechanisms

The current article replicated that people perceive faces with limbal rings as healthier than those without while using a different set of target stimuli than prior investigations, providing robust support that the perceptual differences of faces with(out) limbal rings are not solely because of the stimuli of Peshek et al. (2011). The current article also supported the perceived lightning of the sclera as the mechanism that causes this effect, rather than the characteristics of limbal rings themselves. These findings together aid in countering the argument that empirically observed differences in perceptions of faces with(out) limbal rings are not reliable or valid. These differences are instead a replicable phenomenon with explainable and testable mechanisms, and they should be viewed as an important aspect of facial perceptions and assessments of fitness.

Supporting a specific mechanism for the perceptual differences can also rule out alternative explanations. We did not find support that limbal rings themselves cause faces to be perceived as healthier and more attractive. Although limbal rings fade in old age (Coroneo et al., 2023; Shyu & Wyatt, 2009), they may be difficult to readily perceive. Instead, the larger sclera may be easier for people to consciously or subconsciously perceive as an indicator of health, causing limbal rings to produce effects via their contrast with the sclera rather than independent causes. Similarly, limbal rings aid in gaze detection (Emery, 2000; Kobayashi & Hashiya, 2011). By showing that limbal rings are not independently related to perceived health or attractiveness, our study suggests that the potential evolutionary benefits of limbal rings for gaze detection are not strong enough to influence modern-day perceptions. Eliminating these possibilities enables future research to progress in a more directed manner, such that these alternative explanations do not need to be considered when devising studies to test the dynamics of limbal ring perceptions.

Differences in Results by Stimuli

Not all of our findings were consistent with prior research. In the current article, Studies 1, 2, and 3 did not support that limbal rings or lightened sclerae cause participants to perceive faces as more attractive when using our created stimuli, but Study 4 and prior studies (Brown & Sacco, 2018; Brown et al., 2019, 2020; Sacco et al., 2019) supported that faces with limbal rings are perceived as more attractive when using the stimuli of Peshek et al. (2011). Similarly, Studies 1, 2, and 3 did not observe an interaction between the eye conditions and facial stimuli gender, but Study 4 and prior studies (Brown et al., 2020; Sacco et al., 2019) produced a significant interaction effect. Specifically, Study 4 and prior studies found that the differences in perceptions of faces with(out) limbal rings are stronger when women rate male faces rather than female faces. These divergent findings seem to have arisen because of the applied stimuli given the clear differentiation in results, which opens a multitude of directions for future research.

Our stimuli were created from faces judged to be average attractiveness from the Chicago Face Database normed data (Ma et al., 2015). We specifically chose these average-attractiveness images to ensure that our observed effects would not be because of selecting target pictures that were particularly (un)attractive. When comparing the EMMs of Studies 1, 2, and 3 to Study 4, participants' ratings of attractiveness were notably larger for the stimuli of Peshek et al. (2011) than our created stimuli. This suggests that the stimuli used in almost all prior research on limbal rings may be particularly attractive, and differences in the perceived attractiveness of faces with(out) limbal rings may have, in part, arisen because of the attractiveness of these faces. That is, people may not perceive faces with limbal rings as more attractive than faces without limbal rings unless the face meets a minimum threshold of attractiveness. Likewise, this difference in attractiveness also suggests that the interaction effect between gender and the presence of limbal rings may only occur for

faces that are particularly attractive, such that perceptions of attractive male faces are more influenced by limbal rings than unattractive male faces.

These differences in stimuli and corresponding findings align with research on short-term mating motivations (Brown & Sacco, 2018; Peshek et al., 2011; Sacco et al., 2019). When women are more attuned to short-term mating motivations—or primed to think about short-term mating—they tend to focus more on health cues for members of the opposite sex if attracted to men (Brown & Sacco, 2018; Peshek et al., 2011; Sacco et al., 2019). Because our stimuli were created from faces that were judged to be moderately attractive, the women in Studies 1, 2, and 3 may have been less focused on health cues because they were not particularly primed to think about short-term mating motivations, and in turn, they may have perceived less of a difference in attractiveness between faces with(out) limbal rings because of their potentially reduced short-term mating motivations. On the other hand, because the stimuli of Peshek et al. (2011) seem to be particularly attractive, the women in Study 4 and prior studies may be subconsciously more focused on health cues because they are primed to think about short-term mating motivations, and in turn, they may perceive a greater difference in the attractiveness between faces with(out) limbal rings because of their potentially greater short-term mating motivations.

Additionally, our created stimuli and those of Peshek et al. (2011) contain several other differences, which could potentially cause divergences in observed results. The people within the Chicago Face Database (Ma et al., 2015) are all wearing the same clothes (a gray t-shirt), whereas those within the stimuli of Peshek et al. (2011) are wearing a variety of outfits, including t-shirts, jackets, and one wearing a suit-and-tie. The variation in this cue may cause specific images to produce differing effects, producing overall differences in observed relations. Also, our created stimuli include a natural range of eye colors, whereas almost all images in the stimuli of Peshek et al. (2011) are a shade of light green. It is possible that certain perceptions associated with limbal rings, such as attractiveness, only occur for specific eye colors. Finally, a number of undetected differences may be present across the two sets of stimuli, such as the average prototypicality of faces, the size of certain facial features, or even the color of hair. It is possible that a number of these features—or specific combinations—produce differences in how people perceive facial features, including limbal rings, thereby influencing observed results.

Fortunately, the development of our stimuli and approach to creating them enables a systematic method to explore these possibilities and enhance the theoretical sophistication of research on limbal rings. We identified a database of over 800 photos that can now be utilized to create new target stimuli, such that researchers can more readily investigate the research directions identified in the current article and prior research. Researchers could use this database to create new stimuli of faces judged to be both particularly unattractive and attractive, and they could experimentally test whether the attractive faces produce larger perceptional differences regarding faces with(out) limbal rings. In doing so, they could provide firmer evidence for the relevance of short-term mating motivations in the occurrence of this effect. Likewise, researchers could create stimuli that differ on any number of features, as the Chicago Face Database (Ma et al., 2015) includes normed participant ratings of photos for many characteristics (e.g., masculine) and measured attributes of specific facial features (e.g., nose length). Researchers could test, for example, whether the size or color of eyes influences perceptions of limbal rings. Finally, providing our methodology to create these stimuli also enables the experimental comparison of certain features. For instance, Peshek et al. (2011) suggested that researchers should test limbal rings of different width and darkness. Our process outlined in Section A in the additional online materials can be used to develop these stimuli quite easily in conjunction with the Chicago Face Database (Ma et al., 2015) to heed these calls of prior authors. It can also be used to address many of the limitations of the current work discussed further below.

Boundary Conditions

Future research should probe these possibilities and determine the boundary conditions of differences in perceptions of faces with(out) limbal rings. In addition to creating stimuli with new faces, researchers should also consider manipulating other aspects of faces to create new stimuli. Namely, because our results supported that limbal rings influence perceptions via contrasts with the sclera, limbal rings may have little effect if the

surrounding sclera is discolored, especially considering that discolored sclerae are a sign of worse health (Provine et al., 2013; Russell et al., 2014). In this case, the sclera color would be a potential boundary condition to the influence of limbal rings, which could provide further support for the current inferences if found.

Future researchers should also test further between-person factors. Extant research has typically studied between-person factors associated with short-term mating motivations, such as perfectionism (Sacco et al., 2019) and relational insecurity (Brown et al., 2020), and several other untested personal characteristics may likewise fall into this category. For instance, life history strategy (Kim et al., 2018) and temporal orientations (Wang et al., 2021) are associated with short-term mating strategies, and thereby these individual differences may influence responses to limbal rings. More broadly, the COVID-19 pandemic pushed discussions of health to the forefront of public discourse (Howard, 2020, 2023), perhaps widely heightening sensitivities to health cues. Future researchers should assess whether individual differences associated with health sensitivities influence responses to limbal rings, such as infection anxiety (Peteet, 2020), as these investigations could provide further support that perceptions of lightened sclerae are indeed reflective of assessments of health.

Limitations and Additional Future Research Directions

Stimuli

Our target stimuli were solely faces perceived to be white, which was an intentional decision because people of certain races are more likely to have darker sclerae (Blake et al., 2003). Lighter sclerae may not be associated with perceived health or attractiveness for these people, which could introduce heterogeneity into any observed effects when not explicitly modeled. Future research, however, should create target stimuli and include participants of differing races to determine whether limbal ring perceptions broadly generalize. Doing so could heed calls in psychological research to move beyond white samples (Cheon et al., 2020) and Western, educated, industrialized, rich, and democratic (Henrich et al., 2010). Fortunately, the Chicago Face Database (Ma et al., 2015) includes people of many races, enabling future researchers to easily heed this call by creating new target stimuli with our step-by-step instructions (Section A in the additional online materials).

Similarly, our target stimuli were chosen based on their perceived attractiveness. Because research has supported that limbal ring perceptions are associated with short-term mating preferences (Brown & Sacco, 2018; Brown et al., 2019, 2020; Sacco et al., 2019), the attractiveness of target stimuli may affect the magnitude of observed differences in perceptions of faces with and without limbal rings. The differences in perceptions of faces with(out) limbal rings may be less pronounced for unattractive faces and more pronounced for attractive faces, as participants may be more primed to consider short-term mating preferences for the former than the latter and thereby more focused on the perceived health of attractive faces than unattractive faces. Choosing solely moderately attractive target stimuli reduced the potential heterogeneity in our observed effects, as we did not intend to model the variance of facial attractiveness, and it also enables a more systematic approach to investigating limbal rings in future research. For instance, the characteristics of Peshek et al.'s (2011) target stimuli are relatively unclear because a defined approach was not provided in the selection of the images. By testing moderately attractive faces, we provide baseline stimuli that can be compared against other images in the Chicago Face Database (Ma et al., 2015) to determine variations in limbal ring perceptions by attractiveness, as this database provides normed data that can be utilized to select more and less attractive faces. Future research should test differences of attractiveness, as such an investigation could provide further support for the differences in perceptions of faces with(out) limbal rings and their association with short-term mating preferences.

To create our target stimuli, we did not alter the natural eye colors of the faces, as we did not want to introduce a potential confound in our studies by creating uncommon combinations of eye colors and facial features. For this reason, heterogeneity was potentially introduced in our observed effects because the differences in perceptions of faces with(out) limbal rings may not occur for all eye colors equally. Notably, limbal rings are more difficult to observe for darker irises. A future study on whether the differences in perceptions of faces with(out) limbal rings generalize

across eye colors could also provide further insights into how limbal rings influence perceptions of health. Prior research has supported that faces with brighter eyes are perceived as healthier; these faces are perceived as having greater facial luminance, and facial luminance is associated with greater health (Jones, 2018; Jones et al., 2016). At the same time, brighter eyes may be more likely to blend with the sclera, causing the sclera to appear less bright. Limbal rings on bright eyes may provide the "best of both worlds." That is, the brightness of the eye may increase facial luminance, whereas the limbal ring may still enable the eye to produce a stark contrast with the sclera—thereby causing it to appear lighter. These proposals are only conjecture, however, without empirical support, and future research should assess the dynamics between eye color and limbal rings to better understand the mechanisms of perceived health and attractiveness. Again, our step-by-step instructions and the Chicago Face Database (Ma et al., 2015) can relatively easily produce the target stimuli to investigate these questions.

Research Design

We only administered measures of health and attractiveness because of the focus on these two outcomes in research on limbal rings. In broader research on perceptions of eyes, researchers have studied a wide array of outcomes including perceived trustworthiness and purity (Ilicic et al., 2016; Kleisner et al., 2013). The authors have argued that perceptions of health and attractiveness associated with eyes are often generalized to other positive perceptions, and therefore limbal ring perceptions may need to be reconceptualized to include positive perceptions more broadly. Likewise, our study solely relied on self-report. The perceptions of limbal rings may also produce certain behaviors or physiological responses, such as gaze detection and skin conductivity. Future researchers should move beyond the two central perceptions studied in the current article and investigate broader perceptions, behaviors, and physiological indicators.

It should also be highlighted that, although we proposed that our effects were because of the perceived lightening of the sclera, we did not directly ask participants about their perceptions of sclerae brightness. We made this methodological decision for two primary reasons. Prior studies likewise ask participants about the perceived health and attractiveness of faces rather than specific perceptions regarding eyes when studying limbal rings. Because we wanted our results to advance prior findings in the literature, we ensured that our research design was similar to prior investigations. Perhaps more importantly, we also did not want to introduce a demand characteristic into our study and obtain biased results. Differences in perceptions of faces with(out) limbal rings are believed to occur in a relatively subconscious manner, such that participants may not recognize exactly why they perceive certain faces as healthier or more attractive—or even if they perceive these differences at all. By asking participants directly about the brightness of the sclera, they may become more cued onto the differences in our stimuli and overly focus on this aspect of faces. In doing so, participants may no longer respond naturally, and they may begin to more consciously affix their attention to the eyes of the stimuli. Nevertheless, future researchers may want to consider whether directly asking participants about the brightness of the sclera can provide novel theoretical insights, especially if a methodological approach can be identified that reduces the demand characteristics placed on participants.

We utilized a within-person research design. This design was chosen to align our studies with prior research, as all studies on limbal rings have utilized within-person research designs (Brown et al., 2019; Ilicic et al., 2016; Sacco et al., 2019). This design also enables direct comparisons of perceptions within the same participants, addressing certain methodological concerns when assessing differences in comparisons (Hair et al., 2019). At the same time, this design does increase participant fatigue, and participants may respond differently when seeing similar images multiple times. Future researchers should replicate prior studies on limbal rings with between-subjects designs. Although these designs have methodological concerns of their own (Hair et al., 2019), they can provide evidence that limbal ring perceptions may function similarly across participants when viewing similar images only once. By replicating findings with multiple research designs, a more robust cumulative field of research can be obtained.

In Studies 1 and 2, we were solely interested in the direct comparison of faces without limbal rings, faces with limbal rings, and faces with lightened sclerae. We did not have any rationale to propose interaction effects and/or direct

comparisons of faces with both limbal rings and lightened sclerae. To align with our theoretical rationale, we applied a fractional factorial design that did not include a condition consisting of faces with both limbal rings and lightened sclerae (Gunst & Mason, 2009). This design also enabled us to keep participant fatigue to a minimum, as each condition would require participants to view a significant number of faces and potentially reduce overall data quality. In performing our analyses, we treated our three stimuli manipulations as separate conditions, as our interpretations were focused on pairwise comparisons—both similarities and differences. Future researchers, however, should replicate the current results while utilizing a full factorial design, which would include four conditions for our stimuli: faces without limbal rings, faces with limbal rings, faces with lightened, and faces with both limbal rings and lightened sclerae (2×2). By doing so, researchers could identify the occurrence of any interaction effects, and they could again provide a more robust cumulative field of research by supporting the present effects using varied research designs.

Our study allowed participants to complete the procedures in a location of their choosing to ensure maximum participant anonymity and confidentiality. This decision reduced the overall standardization of procedures, and future research should replicate the current findings with complete standardization in a laboratory setting to ensure maximum internal validity.

Conclusion

The primary goal of the current article was to ascertain the cause of the differences in perceptions of faces with(out) limbal rings, and the results of four studies supported the assertions of prior researchers: the differences in perceptions are because of the perceived lightening of the sclerae. Achieving our primary goal enables future researchers to investigate the limbal rings with more assurances for the validity of their results, and it also provides direction for future investigations into the mechanisms surrounding perceptions of limbal rings. Our empirical approach also improves the soundness of future research on limbal rings, enabling the current article to provide both theoretical and methodological insights. The guidance provided by the current article can be used to develop many additional studies on limbal rings, benefitting broader research on facial perceptions, fitness perceptions, and evolutionary psychology.

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