# A role for contrast gain control in skin appearance

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**Apparent contrast can be suppressed or enhanced when presented within surrounding images. This contextual modulation is typically accounted for with models of contrast gain control. Similarly, the appearance of one part of a face is affected by the appearance of the other parts of the face. These influences are typically accounted for with models of face-specific holistic processing. Here we report evidence that facial skin appearance is modulated by adjacent surfaces. In four experiments we measured the appearance of skin evenness and wrinkles in images with increased or decreased contrast between facial skin and adjacent image regions. Increased contrast with adjacent regions made facial skin appear more even and less wrinkled. We found the effect whether faces were presented upright or inverted, and also when facial features were not present, ruling out face-specific holistic processing as an explanation yet fully consistent with contrast gain control. Because the mechanism is not face specific, contrast between skin and any adjacent surface should affect skin appearance. This suggests that adornments such as makeup, hair coloring, clothing, and jewelry could also affect skin appearance through contrast suppression or enhancement, linking these cultural practices to the structure and function of the visual system.**

> "Give me mud and I will make the skin of Venus out of it, if you will allow me to surround it as I please."
> —Eugène Delacroix

## Introduction

Faces have a privileged role in the brains and visual experience of humans and other primates (Tsao & Livingstone, 2008). The visual world is perceived in terms of contrast, and faces contain unique patterns of contrast that are critical for face perception. In particular, horizontally oriented contrast (Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler, & Bennett, 2013) around the eye/eyebrow and lip regions (Ohayon, Freiwald, & Tsao, 2012; Sinha, 2002) has been shown to be broadly important for face processing and the selectivity of face-specific neurons. The contrast between facial features and the surrounding skin, termed *facial contrast*, is a cue for perceiving age (Porcheron, Mauger, & Russell, 2013; Porcheron et al., 2017), sex (Jones, Russell, & Ward, 2015; Russell, 2009), attractiveness (Russell, 2003; Störmer & Alvarez, 2016), and health (Russell et al., 2016) from the face, and is modified by typical applications of makeup (Etcoff, Stock, Haley, Vickery, & House, 2011; Jones et al., 2015; Russell, 2009; Stephen & McKeegan, 2010). These face-specific patterns of contrast are related to the distinctive midrange band of spatial frequencies that underlie face perception (Keil, 2008; Näsänen, 1999).

While face perception is dominated by these middle spatial frequencies, higher spatial frequencies (i.e., finer details) are important for the visual perception of skin

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because of variation in skin structure that exists on a smaller spatial scale. Also, overall complexion is perceived in the lower spatial-frequency band. The physical and visual structure of skin is complex (Debevec et al., 2000). Reflectance patterns and 3-D surface structures of skin vary with both age and health and play important roles in several core aspects of person perception, including perceptions of age, health, and attractiveness (Fink, Grammer, & Matts, 2006; Fink, Grammer, & Thornhill, 2001), as well as trustworthiness and related traits (Tsankova & Kappas, 2016). Attractive skin is strongly desired, and people spend significant amounts of time and money attempting to improve their skin appearance.

Previously, we made the anecdotal observation that facial skin appearance is affected by changing the color and luminance of the facial features in ways that increase or decrease facial contrast (Porcheron et al., 2013, p. 4). We attributed this effect to the fact that faces are processed holistically, involving less decomposition into parts and greater spatial integration than other objects (Farah, Wilson, Drain, & Tanaka, 1998), including for judgments of facial age (Hole & George, 2011). Similarly, a recent psychophysical study found that lip color affects perceived skin lightness, and the authors proposed that this is due to holistic processing (Kobayashi, Matsushita, & Morikawa, 2017). Yet there is another way that contrast around the facial features might affect the appearance of surrounding skin, based on observations that apparent contrast can be modulated by surrounding image content (Bex, Mareschal, & Dakin, 2007). For example, Chubb, Sperling, and Solomon (1989) found that the apparent contrast in a target patch of random visual texture is affected by surrounding background texture such that if the surround has higher contrast, the target patch appears to have lower contrast (suppressed contrast). Contextual modulation of contrast is typically accounted for by models of contrast gain control (Geisler & Albrecht, 1992; Heeger, 1992; Morrone, Burr, & Maffei, 1982), based on mutual inhibition of the activity of neurons in primary visual cortex via divisive normalization.

Thus there are two distinct processes by which manipulating the facial features might affect the appearance of the surrounding skin: holistic face processing and contrast gain control. Holistic processing is a comparatively high-level process believed to operate within face-specific cortical regions and apply only to face images. Contrast gain control is a comparatively low-level process believed to operate within primary visual cortex, regardless of image content. If the effect is due to holistic processing, it should be disrupted by image manipulations that disrupt holistic face processing, such as inversion (McKone & Yovel, 2009), and it should be present only in images perceived as faces. If the effect is due to contrast gain control, it should be unaffected by image inversion and should be present in images not perceived as faces. Determining whether the effect is face specific will thus help determine the underlying process. But the face specificity of the effect also has applied relevance, in terms of predicting the contexts in which it plays a role.

Here we experimentally tested the hypothesis that manipulating the luminance and color of the facial features affects the appearance of facial skin. We found clear evidence for this contextual modulation of skin appearance in Study 1. In Studies 2–4 we conceptually replicated the finding and tested whether the effect was face specific. All the studies used the same general method, with images manipulated to increase or decrease contrast between skin and adjacent regions by manipulating the adjacent regions but leaving the skin unchanged. Participants were explicitly directed to look at the skin appearance with the task of rating how even and how wrinkled the skin appeared. Evenness and wrinkles are two common properties of skin that are easily assessed by lay observers and are commonly measured in literatures on skin appearance (Batres et al., 2019b; Fink et al., 2001; Nkengne et al., 2008). In this way we investigated the effect of the contrast manipulation on explicit ratings of skin appearance. In Study 1, we manipulated the luminance and color of the eyebrows, eyes, and lips. In Study 2 we presented the same images upside down to determine whether inversion disrupts the effect. In Study 3 we manipulated the color and luminance of bars that occluded face images, and in Study 4 bars occluded images of skin patches rather than entire faces.

To preview the results: We found contextual modulation of skin appearance in every study, regardless of whether the face was upright or inverted, whether the context was part of the face, and even when no face was present in the image. This non-face-specific pattern is consistent with contrast gain control but not with face-specific holistic processing. The results suggest that skin appearance is affected by contrast gain control.

# Study 1

## Method

### *Stimuli*

We used the stimulus set created for study 3 of Porcheron et al. (2013). Thirty white female targets were photographed under constant camera and lighting conditions with neutral expressions, no adornments, and closed mouths. Ten targets were aged 23–34 years, 10 were aged 38–45 years, and 10 were aged 51–59 years. The full-face images were manipulated using Adobe Photoshop CS4 in Lab color mode to create versions with increased or decreased facial contrast. The set was designed to imitate the differences in facial contrast between older and younger adult faces (Porcheron et al., 2013; Porcheron et al., 2017). This was achieved by modifying the luminance and color of the eyebrows, eyes, and lips while leaving the rest of the face—including the skin—unchanged. Spatial definition of the eyebrows, eyes, and lips is shown in Porcheron et al. (2013, figure 1). To increase facial contrast, the eyebrows and eyes were darkened (decreased $L^*$), the eyes were made less red and less yellow (decreased $a^*$ and $b^*$), and the lips were made more red (increased $a^*$) and less yellow (decreased $b^*$). To decrease facial contrast the opposite changes were made. The eyebrows were manipulated using the Photoshop burn tool, in order to selectively darken or lighten the hairs of the brows but not the skin behind them. For the eyes and lips we used the lasso tool to hand-select the pixels of those features and increased or decreased the $L^*$, $a^*$, or $b^*$ channel of the entire selected region.

The images were created with the goal of determining whether facial contrast influences age perception, and so we selected for each face the magnitude of change for each feature that seemed to maximize the change to apparent age while maintaining a naturalistic appearance. In practice, the magnitude of the manipulation was the same for most faces, but in some faces it was weakened in order to maintain a naturalistic appearance. Because we selected the magnitude of contrast adjustment on an ad hoc basis with the goal of increasing the apparent effect on age perception, this may have also increased the effect on skin evenness and wrinkles, since age perception relies in part on skin appearance. This means that while our stimulus set allows us to investigate effects of the *direction* of contrast changes, it does not allow us to investigate or make claims about the *magnitude* of contrast changes, since the magnitude of the changes was not controlled.

This resulted in a total of 60 images, with a high-contrast and a low-contrast version of each of the 30 target faces. Participants were shown these high- and low-contrast versions of the faces but not the original, unmanipulated images. The skin regions of each target face remain physically identical in the high- and low-contrast conditions, which we confirmed by checking RGB histograms of image regions in the forehead and cheek. Example stimuli are shown in Figure 1.

Figure 1. Example stimuli for Study 1. The same target face is shown in both panels. The left image shows the high-contrast version and the right image shows the low-contrast version.

### Participants and procedure

Sixty-six Gettysburg College students (25 male, 41 female), aged 18–22 years old ($M = 19.1$ years, $SD = 1.0$), were recruited through the Psychology Department study pool, and received partial course credit. We sought a large sample size by testing all the study-pool participants available in the given academic term. Subsequent studies used similar or larger sample sizes. All experimental procedures for this and subsequent studies were approved by the Gettysburg College Institutional Review Board and adhered to the tenets of the Declaration of Helsinki.

Participants were instructed that they would view two blocks of faces, in each of which they would see the same faces, for a total of 60 images across the two blocks. The order of the blocks was counterbalanced across participants. In one block, participants were asked, "How smooth or wrinkled is the skin of this person's face?" (1 = very wrinkled, 7 = very smooth); in the other block they were asked, "How even is the skin of this person's face? E.g., has similar coloration throughout, is free of blemishes, spots, dark circles and blotchiness" (1 = very uneven, 7 = very even). Before participants began any ratings, they were shown a short display of all the unmanipulated faces (1,500 ms per face, 500-ms interval) in order to accustom them to the variability of the skin condition within the set, to facilitate their use of the rating scale.

Each of the two blocks contained 30 images, one of each of the 30 target faces. In each block, participants viewed only one contrast version of each target face. Two sets of images were created. Half of the high-contrast versions and half of the low-contrast versions were randomly assigned to one set, and the second set contained the contrast version of each target face not present in the first set. These sets of stimulus images were counterbalanced across participants. Participants saw each target face twice: once in the first block and once in the second. For half the target faces, the high-contrast version was shown in the first block and the low-contrast version in the second block. For the remaining half, the low-contrast version was shown in

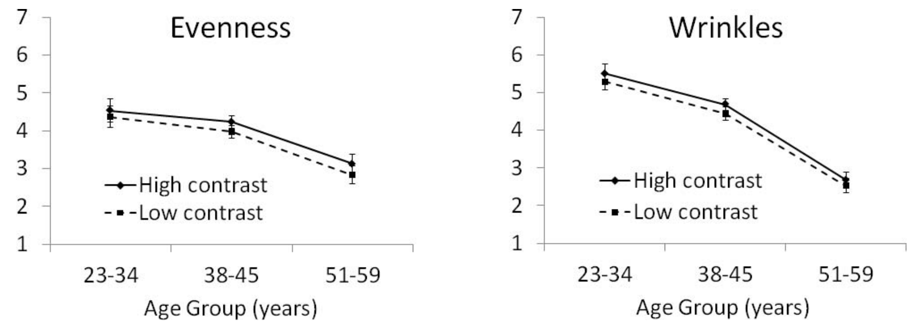


Figure 2. Results of Study 1. The left panel shows ratings of evenness. The right panel shows ratings of wrinkles. Error bars show one standard error of the mean.

the first block and the high-contrast in the second block. This meant that each particular contrast version (high or low) of each face was rated for evenness by half of the participants, and for wrinkles by the other half of the participants. Because of this, we used the item (target identity) as the unit of analysis rather than the participant. Participants rated the images individually and in random order, with age groups and facial-contrast conditions intermixed. Ratings were averaged across participants, resulting in four values for each of the 30 target faces—one each in the high- and low-contrast conditions for ratings of wrinkles and evenness.

### Results

The results of Study 1 are shown in Figure 2. A mixed analysis of variance (ANOVA) was conducted using the item as the unit of analysis, with age (younger, middle-aged, older) as a between-items variable and contrast (high, low) as a within-item variable. For ratings of skin evenness, there were significant main effects of age, $F(2, 27) = 10.3$, $p < 0.001$, partial $\eta^2 = 0.43$, and contrast, $F(1, 27) = 32.4$, $p < 0.001$, partial $\eta^2 = 0.55$, with younger faces and faces with increased contrast appearing to have more even skin. There was not a significant Age × Contrast interaction, $F(2, 27) = 0.7$, $p = 0.52$, partial $\eta^2 = 0.05$. For ratings of wrinkles, there were significant main effects of age, $F(2, 27) = 51.1$, $p < 0.001$, partial $\eta^2 = 0.79$, and contrast, $F(1, 27) = 52.1$, $p < 0.001$, partial $\eta^2 = 0.66$, with younger faces and faces with increased contrast appearing to have less wrinkled skin. There was not an Age × Contrast interaction, $F(2, 27) = 0.9$, $p = 0.41$, partial $\eta^2 = 0.07$.

As expected, older faces were associated with skin that is more wrinkled and less even. Critically, we found a significant effect of facial contrast. Faces with higher facial contrast (increased by manipulating the facial features but not the skin) had skin that appeared more even and less wrinkled than faces with lower facial contrast, even though the skin was physically identical across the conditions.

## Study 2

### Method

Because face-specific holistic processing is disrupted by inversion but contrast gain control is not, Study 2 was identical to Study 1 except that the stimuli were inverted. One hundred ten Gettysburg College students (52 male, 58 female), aged 18–22 years old ($M = 19.1$ years, $SD = 1.2$), were recruited through the Psychology Department study pool and received partial course credit. None of these observers participated in Study 1. The procedures and analyses were identical to those of Study 1.

### Results

The results of Study 2 are shown in Figure 3. For ratings of skin evenness, there were significant main effects of age, $F(2, 27) = 11.6$, $p < 0.001$, partial $\eta^2 = 0.46$, and contrast, $F(1, 27) = 21.4$, $p < 0.001$, partial $\eta^2 = 0.44$, but no significant Age × Contrast interaction, $F(2, 27) = 0.6$, $p = 0.56$, partial $\eta^2 = 0.04$. For ratings of skin wrinkles, there were significant main effects of age, $F(2, 27) = 39.3$, $p < 0.001$, partial $\eta^2 = 0.75$, and contrast, $F(1, 27) = 41.3$, $p < 0.001$, partial $\eta^2 = 0.61$, but no significant Age × Contrast interaction, $F(2, 27) = 1.0$, $p = 0.37$, partial $\eta^2 = 0.07$.

The overall pattern of results was the same as in Study 1. Older faces were associated with skin that appears more wrinkled and less even. Critically, we again found a significant effect of facial contrast. Faces with higher facial contrast (increased by manipulating the facial features but not the skin) had skin that appeared more even and less wrinkled than faces with lower facial contrast. To further test whether the effect

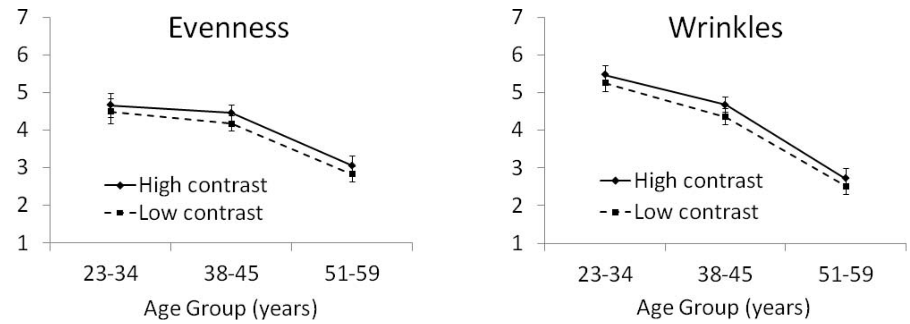


Figure 3. Results of Study 2. The left panel shows ratings of evenness. The right panel shows ratings of wrinkles. Error bars show one standard error of the mean.

was different with upright and inverted faces, we analyzed the results of Studies 1 and 2 together with a mixed ANOVA using the item as the unit of analysis, with contrast (high, low) and orientation (upright, inverted) as within-item variables and age group (younger, middle-aged, older) as a between-items variable. For both ratings of skin evenness[1] and skin wrinkles,[2] there were significant main effects of contrast and age group but not of orientation, and there were no significant interactions among any of the variables. Thus, across Studies 1 and 2 we found that changing the color of the facial features affected the appearance of the facial skin, regardless of the orientation of the face. This is consistent with a low-level contrast mechanism such as contrast gain control, but not with a high-level face-specific mechanism such as holistic processing.

## Study 3

We conducted Study 3 to further test the face specificity of the effect, manipulating contrast with the skin by presenting the target face images behind occluder bars that were either similar to or different from the skin color. Since these occluders are not part of the face, an effect of contrast could be explained by low-level contrast mechanisms but not by face-specific mechanisms. We also explored the generalizability of the effect by using a different set of target faces with a wider age range, and participants from a wider age range.

### Method

#### *Stimuli*

We created stimuli by modifying a subset of images from the FACES database (Ebner, Riediger, & Lindenberger, 2010), which includes full-face, closed-mouth, adornment-free images of white targets photographed in Berlin under constant camera and lighting conditions. Specifically, we selected images of 45 female target faces with neutral expressions. Fifteen targets were aged 19–30 years, 15 were aged 45–55 years, and 15 were aged 69–79 years. The faces were surrounded with an oval mask and occluded by vertical bars over the face. The bars and the spaces between them were each 12 pixels wide. Each face had 12 to 14 bars occluding it. The oval mask and occluding bars were either black ($L^*a^*b^*$ values: 0, 0, 0), hence high-contrast relative to the skin, or a "skin tone" determined by averaging the color of a patch of skin from the middle of the right cheek of all the faces ($L^*a^*b^*$ values: 76, 20, 25), hence low-contrast relative to the faces. This resulted in a total of 90 images, with a high-contrast (i.e., black occluders) and a low-contrast version (i.e., skin-tone occluders) of each of the 45 target faces. Example stimuli are shown in Figure 4.

#### *Participants and procedure*

Sixty-four adults (36 male, 28 female), aged 22–68 years old ($M = 31.2$ years, $SD = 7.7$), who live in the United States were recruited using Amazon Mechanical Turk and paid US $2 for their participation. Partici-

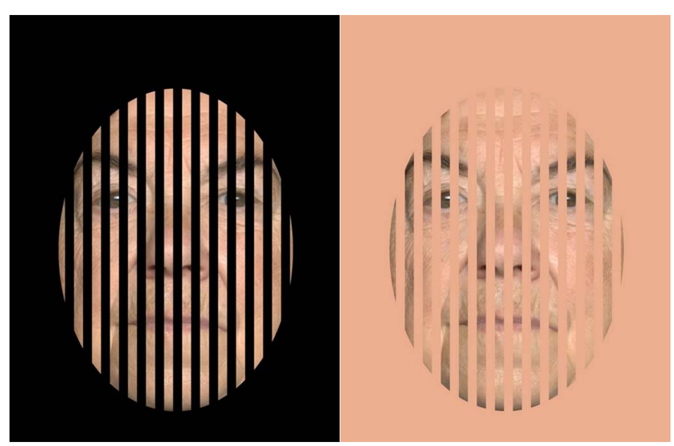

Figure 4. Example stimuli for Study 3. The same target face is shown in both panels. The left image shows the high-contrast version and the right image shows the low-contrast version.

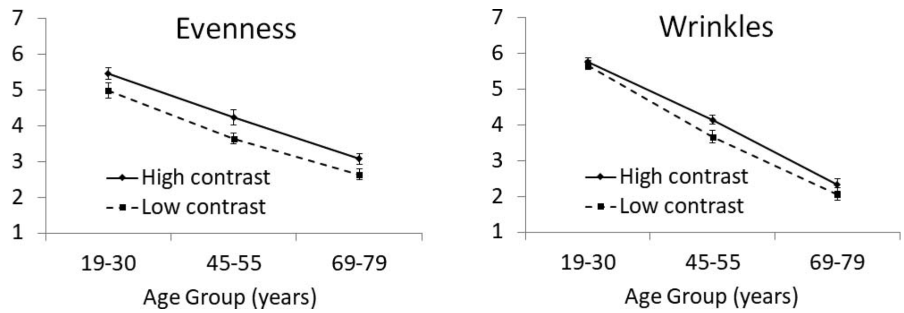


Figure 5. Results of Study 3. The left panel shows ratings of evenness. The right panel shows ratings of wrinkles. Error bars show one standard error of the mean.

pants completed the same tasks as in Studies 1 and 2, rating skin evenness and skin wrinkles. However, because the manipulation would be impossible to conceal from the participants, in Study 3 participants viewed every stimulus image, including both the high- and low-contrast versions of each target face. Nevertheless, for consistency with Studies 1 and 2 we used the item as the unit of analysis (the pattern of results is same if the data are analyzed using the participant as the unit of analysis).

## Results

The results of Study 3 are shown in Figure 5. A mixed ANOVA was conducted using the item as the unit of analysis, with age (younger, middle-aged, older) as a between-items variable and contrast (high, low) as a within-item variable. For ratings of skin evenness there were significant main effects of age, $F(2, 42) = 68.7$, $p < 0.001$, partial $\eta^2 = 0.77$, and contrast, $F(1, 42) = 126.7$, $p < 0.001$, partial $\eta^2 = 0.75$, but no significant Age × Contrast interaction, $F(2, 42) = 1.0$, $p = 0.384$, partial $\eta^2 = 0.05$. For ratings of skin wrinkles, there were significant main effects of age, $F(2, 42) = 176.1$, $p < 0.001$, partial $\eta^2 = 0.89$, and contrast, $F(1, 42) = 47.1$, $p < 0.001$, partial $\eta^2 = 0.53$, as well as a significant Age × Contrast interaction, $F(2, 42) = 7.3$, $p = 0.002$, partial $\eta^2 = 0.26$. To examine the interaction for wrinkle ratings, we conducted repeated-measures ANOVAs separately for each age group with contrast as the only independent variable. We applied a Bonferroni correction for three comparisons, setting $\alpha = 0.017$. There was no significant difference between the high- and low-contrast conditions for the younger age group, $F(1, 14) = 2.1$, $p = 0.173$, partial $\eta^2 = 0.13$, but there were significant differences for the middle-aged group, $F(1, 42) = 35.1$, $p < 0.001$, partial $\eta^2 = 0.72$, and the older age group, $F(1, 42) = 17.8$, $p = 0.001$, partial $\eta^2 = 0.56$. Increased contrast affected the appearance of wrinkles in the middle-aged and older faces but not in the younger ones.

The overall pattern of results was the same as in Studies 1 and 2. Older faces were associated with skin that is more wrinkled and less even. Critically, we again found a significant effect of contrast. Increased contrast between the occluders and the face resulted in the facial skin appearing more even and less wrinkled. An exception was that the appearance of wrinkles in the youngest faces was unaffected by contrast, possibly due to a ceiling effect. The effect of contrast with unrelated adjacent surfaces on skin perception is consistent with a low-level contrast mechanism such as contrast gain control, but not with a high-level face-specific mechanism such as holistic processing.

# Study 4

To further test the face specificity of the effect, Study 4 used stimuli without faces—square patches of cheek skin occluded by a grid of occluding bars. This manipulation is not unlike the appearance of fishnet stockings or a veil across the skin. Contrast was manipulated by making the occluders either similar to or different from the skin color. An effect of contrast is predicted by low-level contrast mechanisms but not by face-specific mechanisms, since no face was present in the image.

## Method

### *Stimuli*

We took square image regions of the cheek skin of the face images used in Study 3. The skin patches were then surrounded with a larger square region and occluded by a grid of vertical and horizontal bars. The bars were each 10 pixels wide or tall. The spaces between the bars were each 30 pixels wide or tall, except for the spaces around the edges of the patches. Each patch was occluded by eight vertical and eight horizontal bars. The occluding grid was either black ($L^*a^*b^*$ values: 0, 0, 0), hence high-contrast relative to

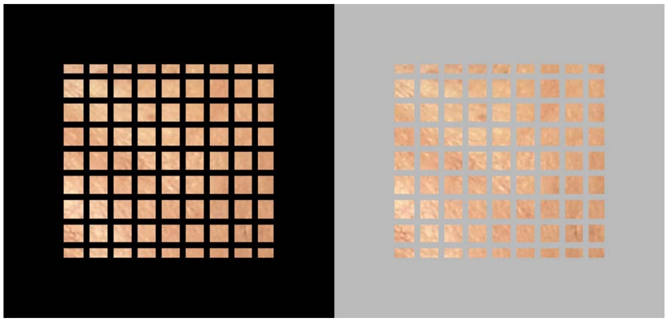

Figure 6. Example stimuli for Study 4. The same skin patch is shown in both panels. The left image shows the high-contrast version and the right image shows the low-contrast version.

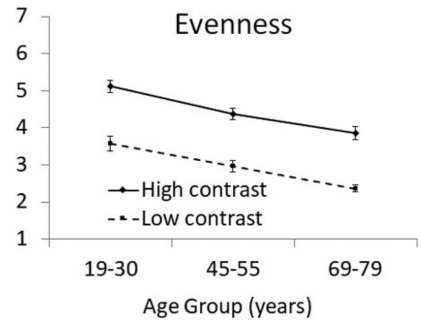


Figure 7. Results of Study 4. Ratings of evenness. Error bars show one standard error of the mean.

the skin, or an achromatic "skin tone" ($L^*a^*b^*$ values: 76, 0, 0), hence low-contrast relative to the skin patches. The achromatic skin-tone color was produced by making the Study 3 skin tone grayscale (i.e., zeroing the $a^*$ and $b^*$ values), such that it had approximately the mean luminance of the skin patches. This resulted in a total of 90 images, with a high-contrast (i.e., black occluders) and a low-contrast version (i.e., achromatic skin-tone occluders) of each of the 45 target faces. Example stimuli are shown in Figure 6.

#### *Participants and procedure*

Fifty-nine adults (38 male, 21 female), aged 21–63 years old ($M = 33.8$ years, $SD = 10.8$), who live in the United States were recruited using Amazon Mechanical Turk and paid US $1 for their participation. Participants completed the same evenness rating task as in Studies 1–3, but did not perform the wrinkles task, as wrinkles were mostly not apparent in the cheek patches. As in Study 3, participants viewed every stimulus image, including both the high- and low-contrast versions of each skin patch.

### Results

The results of Study 4 are shown in Figure 7. A mixed ANOVA was conducted using the item as the unit of analysis, with age (younger, middle-aged, older) as a between-items variable and contrast (high, low) as a within-item variable. For ratings of skin evenness, there were significant main effects of age, $F(2, 42) = 17.1$, $p < 0.001$, partial $\eta^2 = 0.45$, and contrast $F(1, 42) = 505.8$, $p < 0.001$, partial $\eta^2 = 0.92$, but no significant Age × Contrast interaction, $F(2, 42) = 0.4$, $p = 0.659$, partial $\eta^2 = 0.02$.

Although participants viewed patches of skin rather than full-face images, the overall pattern of results was the same as in Studies 1–3. Older skin was perceived as less even. We again found a significant effect of contrast. Increased contrast with the occluders caused the skin to appear more even.

## General discussion

We hypothesized that the appearance of skin evenness and wrinkles is modulated by the color and luminance of the facial features. In Study 1, facial skin appeared more even and less wrinkled when the features had higher contrast with the skin, but less even and more wrinkled when the features had lower contrast with the skin. Finding evidence for contextual modulation of skin appearance, we sought to determine whether it is caused by face-specific holistic processing or by contrast gain control. The results were not consistent with holistic processing, but were consistent with contrast gain control. Specifically, there was no difference in the effect of contrast on skin appearance whether faces were presented upright (Study 1) or inverted (Study 2). Further, in Study 3 the effect was found when the facial skin was occluded by bars that were different or similar in color to the skin. Since the occluding bars were not part of the faces, this is inconsistent with a face-specific mechanism. Finally, in Study 4 high- and low-contrast occluding bars placed over skin patches affected the perception of skin evenness. Since these stimuli contained no faces, the results are consistent with contrast gain control but not with holistic processing. The findings demonstrate contextual modulation of skin appearance and suggest a role for contrast gain control in the perception of skin appearance, and hence in the perception of faces and people.

Contrast gain control has been studied mostly with artificial stimuli such as sine-wave gratings, with some recent work using natural scenes (Alam, Vilankar, Field, & Chandler, 2014; Bex et al., 2007; Wallis, Dorr, & Bex, 2015). Because contrast gain control occurs in primary visual cortex, it could be expected to have substantial and widespread downstream consequences in higher visual areas. Our present finding of contextual modulation of skin appearance suggests that contrast gain control has important consequences for high-level vision, specifically the perception of skin, faces, and people. We suspect that contrast gain control may also have consequences for other aspects of high-level vision such as scene perception and visual search.

However, our results do not conclusively rule *in* contrast gain control as the underlying mechanism the way they do rule *out* face-specific holistic processing. Because these were initial tests of a novel phenomenon, we chose methods that are somewhat more exploratory but less precise than those of a psychophysical investigation. Also, in our studies, rather than investigate the effect of texture contrast in one area on perceived contrast texture in another—as in studies such as that by Chubb et al. (1989)—we have investigated the effect of luminance contrast between regions on perceived texture in one of the regions. Future work could use different manipulations, such as occluders with textures of varying spatial frequency and orientation, to further identify the nature of the effect. Also, two alternative possibilities should be evaluated. First, since image contrast affects eye-fixation behavior and attention, it is possible that the contrast manipulation changed how subjects viewed or attended the images, and that this in turn affected perceived skin evenness. Though we think this is unlikely, because subjects were explicitly directed to view the skin and rate it in terms of wrinkles and evenness, data on eye movements or the use of other methods will be necessary to decisively rule out this possibility. Second, it is possible with stimuli such as those used in Studies 3 and 4 that lightness assimilation (as in the Munker–White illusion) makes the skin appear lighter or darker overall, and this overall change in lightness suppress or enhances the appearance of skin wrinkles and blemishes. Future work could test the role of lightness assimilation by including a high-contrast condition with white gratings. If the skin appears more even, this would rule out lightness assimilation. Also, the lightness-assimilation account makes the testable prediction that ratings of overall skin lightness should mediate the effect of contrast on skin evenness and wrinkles. Regardless, the critical finding from the current work—that the underlying mechanism is not face specific—means that the effect of contrast on skin appearance should occur any time that contrast between the skin and adjacent surfaces is modified.

The perception of skin is of particular importance to social interaction. People are motivated to have skin that appears more even and less wrinkled. This concern is understandable, given the important role that skin appearance plays in the perception of age, health, and beauty (Fink et al., 2006; Fink et al., 2001). Previous work has shown that modifying facial contrast also affects the perception of age (Porcheron et al., 2013; Porcheron et al., 2017), health (Russell et al., 2016), and beauty (Russell, 2003; Störmer & Alvarez, 2016). The present findings imply that this occurs in part because facial contrast affects the appearance of the surrounding skin through contrast gain control.

Facial contrast is increased by makeup use, because the products applied to the facial features increase their contrast with the surrounding skin (Etcoff et al., 2011; Jones et al., 2015; Russell, 2009; Stephen & McKeegan, 2010). In this regard, makeup modifies facial appearance in the same ways that we manipulated the stimulus faces in Studies 1 and 2. This implies that the effect of makeup on perceived skin evenness (Batres et al., 2019b) is due not only to products applied directly to the skin, such as foundation, but also to color cosmetics applied to the facial features, such as lipstick and mascara. By increasing facial contrast, these products can suppress the appearance of contrast in the skin, making the skin appear more even. Because skin evenness affects judgments of age, health, and beauty (Fink et al., 2006; Fink et al., 2001), we propose that makeup makes faces appear younger (Russell et al., 2019), healthier (Nash, Fieldman, Hussey, Leveque, & Pineau, 2006), and more attractive (Batres et al., 2019a) in part through the contextual modulation of skin appearance that we have shown here. It has been shown that lip color can affect the perceived lightness and hue of facial skin (Kiritani, Okazaki, Motoyoshi, Tanako, & Ookubo, 2017; Kobayashi et al., 2017). Our findings join these in supporting the claim that makeup applied to the facial features affects skin appearance.

In addition to makeup, the contextual modulation of skin appearance we have shown here may illuminate our understanding of other adornments and decorations adjacent to the skin. Because the contextual modulation of skin appearance is not face specific, skin appearance on any part of the body should be affected by contrast with adjacent surfaces. Such effects likely operate only over small spatial scales, given the evidence that contrast gain control operates within but not across cortical hypercolumns (Bex et al., 2007), consistent with the larger effects here in Study 3 and especially Study 4 compared to Studies 1 and 2. We suspect that veils, stockings, hair, clothing, glasses, and jewelry could be capable of affecting the appearance of adjacent skin regions. Specifically, greater contrast between these surfaces and adjacent skin may cause the skin to appear more even and less wrinkled. However, such effects may not always be large enough to influence person perception. Beards presumably increase contrast with the skin, perhaps making the skin appear smoother—yet beards make faces look older

(Dixson & Vasey, 2012), possibly because beards are associated with adulthood (see Russell et al., 2019, for evidence that makeup makes girls and young women look older because it is associated with adulthood). Nonetheless, the current findings suggest the intriguing possibility that practices of grooming and adornment could utilize contrast gain control to make people appear younger, healthier, and more attractive by changing skin appearance.

*Keywords: divisive normalization, face perception, person perception, cosmetics, makeup*

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## Footnotes

[1] Contrast: $F(1, 27) = 36.8$, $p < 0.001$, partial $\eta^2 = 0.58$; age group: $F(2, 27) = 11.6$, $p < 0.001$, partial $\eta^2 = 0.46$; orientation: $F(1, 27) = 1.9$, $p = 0.18$, partial $\eta^2 = 0.07$; Contrast × Age group: $F(2, 27) = 0.7$, $p = 0.49$, partial $\eta^2 = 0.05$; Contrast × Orientation: $F(1, 27) = 0.2$, $p = 0.70$, partial $\eta^2 = 0.01$; Age group × Orientation: $F(2, 27) = 1.0$, $p = 0.39$, partial $\eta^2 = 0.07$; Contrast × Age group × Orientation: $F(2, 27) = 0.4$, $p = 0.70$, partial $\eta^2 = 0.03$.

[2] Contrast: $F(1, 27) = 85.6$, $p < 0.001$, partial $\eta^2 = 0.76$; age group: $F(2, 27) = 46.3$, $p < 0.001$, partial $\eta^2 = 0.77$; orientation: $F(1, 27) = 0.3$, $p = 0.62$, partial $\eta^2 = 0.01$; Contrast × Age group: $F(2, 27) = 1.7$, $p = 0.20$, partial $\eta^2 = 0.11$; Contrast × Orientation: $F(1, 27) = 0.8$, $p = 0.37$, partial $\eta^2 = 0.03$; Age group × Orientation: $F(2, 27) = 0.2$, $p = 0.86$, partial $\eta^2 = 0.01$; Contrast × Age group × Orientation: $F(2, 27) = 0.2$, $p = 0.80$, partial $\eta^2 = 0.02$.

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