Received: 20 April 2023 | Accepted: 18 June 2023

DOI: 10.1111/ics.12877

International Journal of Cosmetic Science | SOCIÉTÉ FRANÇAISE DE COSMÉTOLOGIE

ORIGINAL ARTICLE

Predictors of female age, health and attractiveness perception from skin feature analysis of digital portraits in five ethnic groups

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Abstract

Objective: Research indicates the impact of skin colour, tone evenness and surface topography on ratings of age, health and attractiveness in women. In addition to subjective assessments, these effects have been quantified with objective measures derived from skin image analysis. Signs of skin ageing may manifest differently across ethnic groups. However, comparisons have been limited to research with two ethnic groups, preventing conclusions about an ethnicity-specific ranking of skin ageing signs.

Methods: We report results from a multi-ethnic and multi-centre study in which faces of women ($n=180$; aged 20–69 years) from five ethnic groups were imaged. Facial images were rated for age, health and attractiveness by members of the same ethnic group (each $n=120$). Digital image analysis was used to quantify skin colour, gloss, tone evenness and wrinkling/sagging. We assessed associations between face ratings and skin image measurements in the total sample (i.e. all ethnic groups) and separately by ethnicity.

Results: Skin image analysis revealed differences between ethnic groups, including skin colour, gloss, tone evenness, wrinkling and sagging. Differences in the relative predictive utility of individual skin features in accounting for ratings of age, health and attractiveness also were observed between ethnic groups. Facial wrinkling and sagging were the best predictors of face ratings in each ethnic group, with some differences in the type (or predictive magnitude) of skin features.

Conclusion: The current findings corroborate previous reports of differences between ethnic groups in female facial skin and indicate differential effects of skin features on ratings of age, health and attractiveness, within and between ethnic groups. Facial wrinkling and sagging were the best predictors of age and attractiveness ratings, and skin tone evenness and gloss had an additional role in ratings of health.

KEYWORDS
cross-cultural, ethnicity, face perception, skin image analysis, women

Résumé

OBJECTIF: La présente étude montre l'impact de la couleur de la peau, de l'uniformité du teint, et de la texture cutanée sur l'évaluation de l'âge, de la santé et de l'attractivité chez les femmes. En plus d'évaluations subjectives, ces aspects ont été quantifiés à l'aide de mesures objectives provenant d'analyse d'image de la peau. Les signes de vieillissement de la peau peuvent se manifester différemment selon les groupes ethniques. Cependant, les précédentes recherches se limitent à des comparaisons entre deux groupes ethniques, empêchant ainsi de conclure sur un classement des signes de vieillissement cutané par ethnie.

MÉTHODE: Nous présentons les résultats d'une étude multiethnique et multicentrique dans laquelle des visages de femmes (n = 180 ; âgées de 20 à 69 ans) de cinq groupes ethniques ont été imagés. Les images des visages ont été évaluées en termes d'âge, de santé et d'attractivité par des membres du même groupe ethnique (n = 120 par groupe). Des algorithmes d'analyse d'image ont été utilisés pour quantifier la couleur de la peau, la brillance, l'uniformité du teint et les rides/affaissement de la peau. Nous avons analysé les corrélations entre l'évaluation des visages et les mesures quantitatives issues de l'analyse d'image sur la totalité de l'échantillon (c'est-à-dire tous les groupes ethniques) et séparément par ethnie.

RÉSULTATS: L'analyse d'image a révélé des différences entre les groupes ethniques, notamment en ce qui concerne la couleur de la peau, la brillance, l'uniformité du teint, les rides et le relâchement cutané. Des différences dans la valeur prédictive relative des différentes caractéristiques cutanées dans l'évaluation de l'âge, de la santé et de l'attractivité ont également été observées entre les groupes ethniques. Les rides et l'affaissement du visage ressortent comme les meilleurs prédicteurs de l'évaluation pour tous les groupes ethniques, avec quelques différences dans le type (ou l'ampleur de la prédiction) des différentes caractéristiques cutanées.

CONCLUSION: Les résultats actuels corroborent les rapports précédents sur les différences entre les groupes ethniques concernant la peau du visage des femmes. Ils montrent également des effets différentiels des caractéristiques cutanées sur l'évaluation de l'âge, de la santé et de l'attractivité, au sein des groupes ethniques et entre eux. Les rides et l'affaissement du visage ressortent comme les meilleurs prédicteurs de l'âge et de l'attractivité, tandis que l'uniformité et la brillance du teint jouent un rôle supplémentaire dans l'évaluation de la santé.

INTRODUCTION

Research documents influences of facial physical characteristics including shape [1] and texture [2] on social perception, suggesting that individuals extract and use information from facial cues in social settings [3, 4]. Although there is variation in attractiveness standards within and between societies, evolutionary scientists have argued that assessments of age, health and attractiveness contribute universally to impression formation [5, 6], leading to inferences about biological and social qualities that affect mating-related preferences [7, 8].

Research on cross-cultural consistency in facial attractiveness assessments has led to mixed conclusions. Evolutionary-based studies report agreement in attractiveness assessments across cultures [9, 10], whereas other research suggests culture-specific strategies in extracting information from faces [11]. Evolutionary adaptations and sociocultural influences likely both contribute to first impressions from faces [12] and disagreement about the determinants of face preferences may be caused by variations in environmental settings [13]. A recent multi-ethnic and multi-centre study [14–16] imaged the faces of women aged 20–69 years in five countries (China, France, India, Japan and South Africa) and secured judgements of age, health and attractiveness by naïve assessors within and across ethnic groups. It was found that differences in judgements of facial appearance depend on the ethnicity of the imaged woman, and the ethnicity and gender of the assessor. These findings suggest that consistent with the literature, for example [6, 17], the age-related decline in perceived attractiveness and health is universal. However, there also was cross-cultural variation, with large differences associated with face and assessor ethnicity, especially in attractiveness and health, suggesting plasticity in perceptions (for a discussion of possible reasons, see [14]).

This research extends previous reports from a multi-ethnic and multi-centre study [14–16] to investigate associations of third-party ratings of age, health and attractiveness of images of female faces with quantitative skin characteristics extracted from these images. Previous research documents the effects of skin colouration (i.e. tone evenness/contrast) and surface topography (i.e. fine lines/wrinkles, sagging) on perceptions of age, health and attractiveness in lightly pigmented women [18–21], even after controlling for the influence of facial shape [2, 22]. In addition to securing assessments by naïve raters, research has quantified skin tone evenness using digital image segmentation, documenting that an objective measure of skin tone evenness (using Haralick's texture features) [23] predicts perceptions of age, health and attractiveness [24]. Increased facial skin yellowness (in terms of CIELAB b^*) and lightness (L^*) have been linked to healthy appearance in lightly pigmented (British) and darkly pigmented (South African) faces, possibly because higher carotenoid levels improve immune defence [25]. Similarly, higher a^* values may signal greater skin blood perfusion and, therefore, enhance the perception of facial health [26]; see [27] for CIELAB definitions.

The manifestation of skin ageing signs has been investigated in different ethnic groups, for example [28–31], although comparisons have often been limited to research with two ethnic groups (e.g. Caucasian vs East Asian, or Caucasian vs Black African). Definitive presentations of an ethnicity-specific ranking of skin ageing signs also have been limited by the use of different protocols and procedures across studies, either in the recording of information (including imaging) of participants or due to study-specific methods of image assessment (e.g. experts vs naïve raters). However, one conclusion is that Caucasians are more susceptible to facial wrinkling/sagging, whereas East Asians are more susceptible to a decrease in skin tone evenness. In addition, facial skin signs of ageing occur later and are less pronounced in non-Caucasian people [32].

Recent research examining the impact of age-related facial features on age assessments in women of five ethnic groups (Chinese, Japanese, French, Indian and South African) reported that differences between chronological age and perceived age varied across ethnic groups, especially so for Indian and South African women [33]. Facial wrinkling/texture and ptosis/sagging were found to be the predominant features affecting perceived age in all five ethnicities (although the size of these effects varied; see [33], followed by skin discolouration and pigmentation disorders). Collectively, these findings indicate ethnic variation in the prediction of age from skin features.

In the Flament et al. study [33], facial signs of ageing were assessed by experts using referential skin ageing atlases and by naïve panellists who estimated age from facial portraits. This study takes a different approach by examining associations of facial signs of ageing derived from skin image analysis of female portraits from five ethnic groups (China, Japan, France, India and South Africa) with naïve assessors' ratings of age, health, and attractiveness. Similar to Flament et al. [33], we consider facial wrinkling and sagging in addition to measures of skin tone evenness and colour(s) of the CIELAB space. However, we did not include skin pores in the analysis as previous work reported little effect on perceived age in most ethnic groups [33].

In this study, we examined associations of age, health and attractiveness ratings with skin image analysis in five ethnic groups, together and separately in each ethnic group. We expected differential effects of wrinkling/sagging and skin tone evenness/contrast on age and health assessments, following previous reports, for example [20], with skin surface topography showing stronger relationships with age assessments than skin discolouration. In contrast, we expected skin colouration and gloss [34] to show stronger relationships with health ratings. We did not expect CIELAB colour measures to predict face ratings, particularly because assessors viewed only faces of their own ethnicity (i.e. there were no cross-ethnicity ratings included, to avoid effects of 'colourism'; [35]). Attractiveness ratings were expected to follow the associations of skin features with age assessments, as previous research has reported a larger effect of the former than the latter in terms of variance explained in attractiveness ratings [20]. Although ethnic differences in the emphasis of facial signs of ageing on perception have been documented (e.g. [32, 33, 36], see [37] for review), the formulation of explicit hypotheses about ethnicity-specific strength of associations of skin features with assessments of female age, health and attractiveness remains difficult. Therefore, analysis of associations between face ratings and skin features by ethnic group was exploratory and findings should be considered with caution given individual variability within- and across ethnic groups.

MATERIALS AND METHODS

Study sample

Facial images and rating data were secured in five locations—Guangzhou (China), Tokyo (Japan), Lyon (France), New Delhi (India) and Cape Town (South Africa)—using experimental equipment and protocols that were part of a larger project on the perception of female physical appearance [14–16].

Five-hundred and twenty-six women ('participants') representing five ethnic groups were recruited through local agencies and consented to have their faces imaged: Chinese ($n=106$), Japanese ($n=100$), French ($n=105$), Indian ($n=100$) and South African ($n=115$). Each sample included participants aged 20–69 years, equally distributed around the mean ages of 10-year cohorts. The facial skin tone of women varied from darkly pigmented to lightly pigmented. According to the Fitzpatrick scale, a widely used photo-type classification tool for UV light sensitivity [38–40]; with type I = lightest pigmentation, and VI = darkest pigmentation, participants corresponded to the following types (as assessed by skin experts at the study centres): Chinese II-IV, Japanese II-IV, French II-III, Indian IV-V and South African V-VI.

Participants were screened before recruitment and women currently pregnant or lactating, suffering from visible facial pathologies or skin disease, receiving treatment for skin disease, involved in another clinical investigation or having participated in such within the past 2 months, having facial tattoos or permanent make-up, having topically applied hydroquinone-containing product within the past 3 months, having a history of facial cosmetic surgery, laser treatment or application of Botox or hyaluronic acid-based fillers were excluded from participation.

All participants provided written informed consent before participating. For images of participants shown in this article, the individuals provided written informed consent for publication. The study was approved by the Reading Independent Ethics Committee (RIEC), Woodley (UK) and the ACEAS Independent Ethics Committee, Ahmedabad (India).

Facial imaging

Participants wore identical black hairbands and black capes to cover features that might affect facial assessments (e.g. head hair, chest or clothes) (Figure 1). Their faces were imaged in frontal view, with eyes open and with a neutral facial expression using the ColorFace® system (Newtone Technologies).

ColorFace® captures high-resolution (24 MPs, at a maximum image size of 4000 × 6000 pixels) full-face images without a chin-rest using an in-built single-lens reflex (SLR) camera (Nikon D5300; Nikon Inc.). Earplugs attached to the stand of the device ensured standardized positioning of participants' faces, with a fixed distance between lens and face. A 48-colour reference chart (ColorChart®, Newtone Technologies) is included in the imaging setup. ColorFace® uses LED light sources on the left and right sides of the face. System settings were selected to reduce the flash intensity and increase the light sensitivity of the camera sensor to avoid disturbance of the participant during imaging. Facial images were recorded under different lighting conditions: cross-polarized to

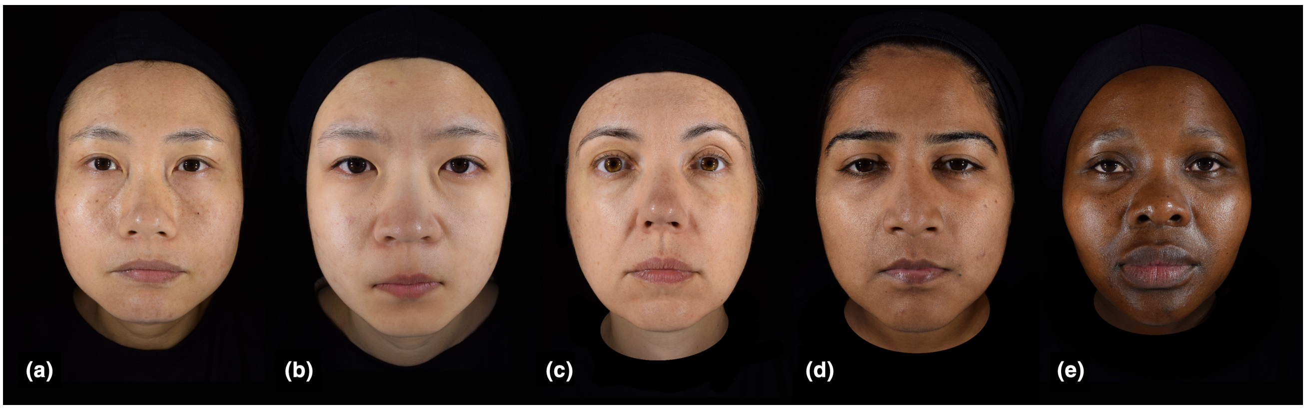

FIGURE 1 Sample images of female participants for presentation in the rating study. Chinese (a), Japanese (b) French (c), Indian (d) and South African (e).

remove specular reflection (for colour measurement), parallel-polarized and at 45° and 60° polarization angles (for the assessment of specular reflection and to better visualize the skin relief) [41]; see [42, 43] for a review. For the presentation of the rating study, earplugs were digitally removed from images, eyes were vertically aligned and the visible area of the neck was standardized across images.

Face ratings

Assessors

A sample of 600 volunteers (299 females) ('assessors') participated in the rating study. They were recruited through local agencies in the same locations (and study centres) where the facial images were recorded. Assessors reported residence in the respective location for at least 2 years. The assessors' skin phototypes matched that of imaged women in each of the five study locations (as assessed on the Fitzpatrick scale by skin experts at the study centres). Thus, we had female and male assessors of five ethnicities ($n = 120$ per location). Each ethnic group included assessors from the ages of 20–66 years equally distributed around the mean ages of 15-year cohorts. The differences in mean ages between adjacent groups were 15 ± 2 years (all $ps < 0.001$).

Image selection

A subset of 180 images (of the initial sample with $n = 526$) was selected for presentation in the rating study, following a quality check for the suitability of images for inclusion in the rating study. Three raters independently assessed the initial image set on a 4-point scale (1 = *not acceptable*, 4 = *acceptable*) for problems with positioning (e.g. head tilted), visibility of neck and artefacts due to digital removal of earplugs. Only images considered 'acceptable' by all three raters were considered for subset selection ($n = 382$). Image selection was randomly stratified for participant/assessor ethnicity, and assessor gender and cohort; thus, of the available set of images, 36 images per ethnicity were assigned to female and male assessors of three cohorts by considering all possible factor combinations. The images were presented on colour-calibrated, light-shielded, 27-inch LCD monitors (ColorEdge CG277, Eizo, Hakusan, Japan) with faces approximating natural size. The distance of the assessor to the monitor during the assessment was 50–60 cm. Room conditions during the assessment were 21 ± 1°C and $45\% \pm 10\%$ relative humidity with artificial light only.

Procedure

Assessors judged the images for age, health and attractiveness in a monadic presentation design (i.e. one after the other). Each assessor judged 90 randomly selected facial images per attribute, balanced across cohorts (i.e. 270 images, in total). Thus, each image was assessed ~300 times in total, 10 times per subgroup (cohort, ethnicity and gender). Assessments of the three attributes were made in three separate blocks, using web-based software (PhotoScale; Newtone Technologies). The continuous scales ranged from 0 to 100, with age assessment provided in years, and attractiveness and health assessments ranging from 'not attractive/not healthy' (0) to 'attractive/healthy' (100). The order of blocks was randomized across participants, as was the order of images within a block. The time for assessment was limited to 3–5 s. (after which the image disappeared) to ensure viewing time was comparable across participants. Breaks of 15 min. were included between blocks to prevent fatigue effects. Statements on the screen and the attributes were created in English and then translated into Mandarin, French, Hindi, Japanese and Xhosa by native speakers and verified by back-translation. In the analyses of this study, we considered only the age, health and attractiveness ratings provided by raters of the same ethnicity as the women's (target faces) ethnicity (i.e. Chinese assessors of Chinese women, Japanese assessors of Japanese women, etc).

Skin image measurements

We defined several regions of interest (ROI) in the individual images for skin image measurements (Figure 2), i.e., full face (1), forehead (2), glabella vertical (3) and horizontal (4) wrinkles, crow's feet (5), the area underneath the eyes (6), upper lips area (7), nasolabial fold (8) and marionette lines (9). Colour, gloss and skin tone evenness were measured in the full face (ROI 1), wrinkles in the ROIs 2–7 and sagging in the ROIs 8 and 9. The measurements from paired ROIs for the analysis of wrinkles/sagging were aggregated by calculating the mean value of both ROIs.

Colour

The skin colour of the face was measured from images in terms of red, green and blue (RGB) colour values, which were then converted into CIELAB colours [44, 45] L^*, a^* and b^* and averaged for all the pixels respectively. The CIELAB colour space is three-dimensional and covers the range of human perception. L^* refers to lightness (from black [0] to white [100]). Negative a^* values indicate green

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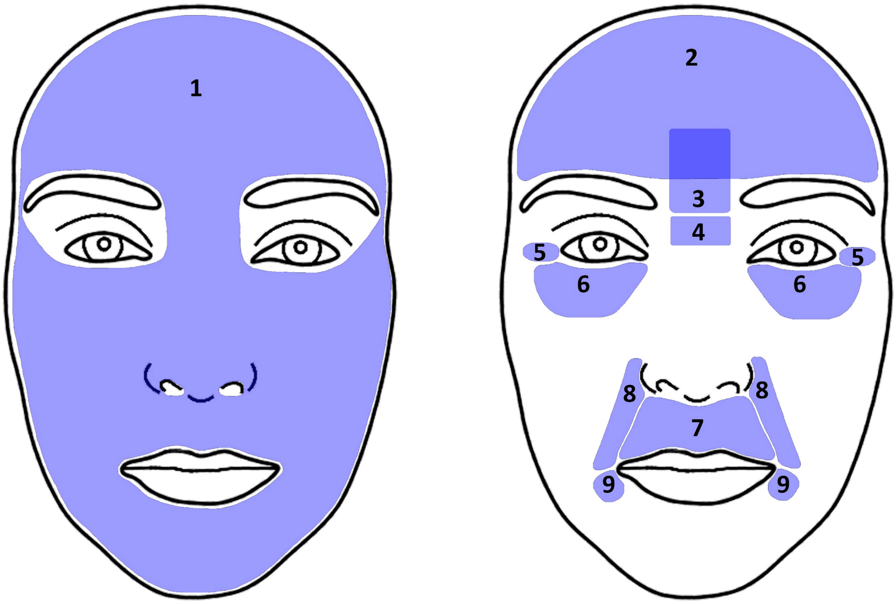

FIGURE 2 Regions of interest (ROIs) in which the skin image measurements were perfomed. Colour, gloss and skin tone evenness were measured in the full face (ROI 1, left), wrinkles in the ROIs 2–7 (right) and sagging in the ROIs 8 and 9 (right).

and positive values indicate red. Negative *b** values indicate blue and positive values indicate yellow.

Gloss

Skin gloss was calculated as the difference between the 60° polarized image and its cross-polarized version. After classifying pixels as bright or matte, two parameters were computed: the specular gloss, defined as the mean luminance of bright pixels in the images, and the contrast gloss, defined as the absolute difference between the mean intensity of bright pixels and the average intensity of matte pixels. Higher specular gloss corresponds to an increase in gloss intensity, and a higher contrast gloss corresponds to higher gloss visibility [34, 46].

Tone evenness

Skin tone evenness was assessed following previous research that applied texture analysis to the assessment of skin colour homogeneity in women [2, 24]. Texture provides information about the spatial arrangement of colours or intensities in an image. We extracted two features based on Haralick's texture measures [23] from grey-level co-occurrence matrices (GLCM). GLCM analysis requires that the images are quantized to a given number of grey levels. Thus, the facial images were converted to greyscale and a Mexican Hat function-based operator (i.e. the second-order derivative of the Gaussian function) [47] was applied to increase contrast in preparation for feature extraction [2]. A co-occurrence matrix is a two-dimensional array which considers information about adjacent pixels (and the probability of their occurrence). Statistical analysis is typically based on numerical features that are computed from the matrix [23, 48]. In this study, we computed two of Haralick's features which have proven successful in quantifying skin tone evenness, that is, homogeneity and contrast [49].

$$\text{Homogeneity} = \sum_{i,j=0}^{N-1} \frac{P_{i,j}}{1+(i-j)^2}$$

where i and j are greyscale values in adjacent pixels, and $P(i, j)$ is the frequency of their occurrence. N is the number of rows or columns of the co-occurrence matrix. Homogeneity measures the closeness of the co-occurrence matrix to a diagonal matrix with the same pixel values for every adjacent pixel. In even skin tones, homogeneity is high as adjacent pairs are more common and the distribution becomes more uniform.

$$\text{Contrast} = \sum_{i,j=0}^{N-1} P_{i,j}(i-j)^2$$

Contrast is a measure of the local variations present in an image. It assigns similar grey level values a low weight and dissimilar grey level values a high weight. Thus, the contrast increases as the difference between adjacent pairs increases, that is, the pixel intensities in a local neighbourhood of a pixel become more disparate. Contrast is high for skin that shows local distribution and concentration of melanin (e.g. hyperpigmentation, solar lentigines) and haemoglobin (e.g. bruising, telangiectasias) (see for review [50]).

Wrinkles/sagging

Wrinkle assessment was performed using a segmentation pipeline including wrinkle highlighting, segmentation, and false-positive cleaning. The facial images were projected on the L^*-axis and filtered to highlight wrinkles. Wrinkles were then identified using an algorithm that detects anisotropic elements (line detection) and retains those elements that are considered wrinkles based on thresholding (i.e. only those lines visible to the investigator were segmented to keep the detection level comparable with that of assessors who provided the face ratings) (see, e.g. [51]). False-positive cleaning was performed using mathematical criteria that considered minimum wrinkle size and length. Using this pipeline, three wrinkle characteristics were computed, that is, conspicuous density, (total) length and (total) volume of the detected wrinkles. The conspicuous density is defined as the ratio between the number of segmented pixels (of a feature) and the size of the ROI. The conspicuous length was measured in pixels, such that a lower value corresponds to smaller wrinkles. The conspicuous volume is calculated from a grey-level depth map as the product of the number of segmented pixels and the depth, the latter defined as the difference in luminosity intensity between the segmentation and the surrounding area. Volume is expressed in an arbitrary unit. Smaller values correspond to lower wrinkle visibility. Across ethnic groups, the wrinkle segmentation algorithm was identical for a given ROI but the mathematical settings (thresholding) were adapted to the respective phototype. The procedure for the measurements of sagging followed that of wrinkles.

Statistical analysis

We report descriptive statistics for the technical measures and health ratings. The one-sample Kolmogorov–Smirnov test for goodness of fit (including Lilliefors correction) was used for testing the normality of the distribution of the variables included in the analysis. Several variables did not meet this criterion; therefore, non-parametric tests were used for the comparison of dependent variables between ethnic groups (one-way ANOVA on ranks; Kruskal–Wallis H test, including post hoc pairwise comparisons). The relationships between third-party face ratings and technical measures from skin image analysis were assessed using multiple regression analysis (for the use of regression models with ordinal variables [52, 53]). We report R^2 (coefficient of determination) for the proportion of variance in dependent measures that can be explained by independent variables (i.e. predictors). In addition, we limit the report to statistically significant predictors and provide unstandardized (B) and standardized (β) coefficients together with information on the significance of the slope (t). The alpha level was set to 0.05. All tests were performed using IBM SPSS 26 (IBM Corp.) and JMP 16 (SAS Institute Inc.).

RESULTS

The distributions of age ($z=0.082$, $p<0.01$) and attractiveness ($z=0.073$, $p<0.05$) but not health ratings ($z=0.066$, $p=0.053$) violated the assumption of normality. Similarly, with two exceptions (CIELAB colours a^* and b^*, both zs <0.062, $p>0.05$), the technical measures included in the analysis violated the assumption of normality (all zs >0.118, $p<0.001$). Skewness scores ranged from −1.14 (specular gloss) to 2.29 (wrinkle volume) and kurtosis from −1.09 to 13.02 (wrinkles volume).

Table 1 reports the descriptive statistics for age, health and attractiveness ratings, and Table 2 reports the descriptive statistics for the technical measures from skin image analysis, split by ethnic group.

Comparison of ethnic groups

Face ratings

Assessors' ratings of women's age ($H=3.35$, $p=0.50$) and attractiveness ($H=8.03$, $p=0.09$) did not differ between ethnic groups. However, health ratings did differ between ethnic groups ($H=50.26$, $p<0.001$). Both Indian and South African ratings were lower versus other ethnic groups, with no difference between Indian and South African ratings ($p=0.13$). There were no differences between Chinese, Japanese and French ratings (all $p>0.05$).

Colour

The ethnic groups differed in the three CIELAB colour measures (L^* $H=143.06$, $p<0.001$; a^* $H=71.38$, $p<0.001$; b^* $H=56.09$, $p<0.001$). French women had the highest L^* values, followed by Chinese, Japanese, Indian and South African women, with pairwise comparisons significant except for Chinese versus Japanese women ($p=0.81$). South African women had the highest a^* values, followed by Indian, French, Chinese and Japanese women. Post hoc tests were significant except for Chinese versus Japanese ($p=0.22$), Chinese versus French ($p=0.12$) and Indian versus South African women ($p=0.79$). Colour b^* values were highest for

TABLE 1 Descriptive statistics for age, health and attractiveness ratings split by ethnic group.

	Chinese	Japanese	French	Indian	South African
Age					
M	43.9	43.4	45.4	46.5	48.0
SD	10.6	13.9	15.1	12.1	12.1
SEM	1.8	2.3	2.5	2.0	2.0
Range	41.8	49.3	47.1	42.9	48.0
Minimum	27.0	21.5	25.5	28.3	21.5
Maximum	68.8	70.8	72.6	71.1	79.1
Health					
M	60.6	63.0	63.6	47.8	52.8
SD	8.0	8.6	11.6	11.2	10.5
SEM	1.3	1.4	1.9	1.9	1.8
Range	33.0	32.5	43.1	45.2	52.3
Minimum	46.3	46.3	39.3	26.2	28.5
Maximum	79.3	78.8	82.4	71.4	80.8
Attractiveness					
M	42.7	38.2	41.3	37.3	38.0
SD	8.9	7.9	13.8	9.3	9.2
SEM	1.5	1.3	2.3	1.6	1.5
Range	41.0	35.1	46.5	36.6	36.4
Minimum	20.9	26.3	17.5	21.8	23.8
Maximum	62.0	61.4	64.0	58.4	60.2

Indian women, followed by Chinese, South African, Japanese and French women. Pairwise tests were significant except for Chinese versus Japanese ($p=0.065$), Chinese versus South African ($p=0.47$) and Indian versus South African women ($p=0.18$).

Gloss

Contrast gloss ($H=129.20$, $p<0.001$) and specular gloss ($H=131.29$, $p<0.001$) differed between ethnic groups. Contrast gloss was highest in South African women, followed by Indian, Japanese, Chinese and French women. For contrast gloss, post hoc tests were significant except for Chinese versus French women ($p=0.09$) and Chinese versus Japanese women ($p=0.33$). Pairwise tests for specular gloss were significant except for Chinese versus Japanese ($p=0.87$), Chinese versus French ($p=0.39$) and Japanese versus French women ($p=0.30$).

Tone evenness

Differences between ethnic groups were detected for skin tone evenness (homogeneity $H=135.47$, $p<0.001$; contrast $H=132.32$, $p<0.001$). Homogeneity was highest for French women, followed by Japanese, Chinese, Indian and South African women, with no difference for Chinese versus Japanese ($p=0.93$), Chinese versus French ($p=0.17$) and Japanese versus French women ($p=0.15$). Contrast was highest for South African women, followed by Indian, Chinese, Japanese and French women. Pairwise tests showed no difference for Chinese versus Japanese ($p=0.32$), Japanese versus French versus ($p=0.39$) and Indian versus South African women ($p=0.44$).

Wrinkles

The density of wrinkles differed between ethnic groups ($H=14.99$, $p<0.01$), with the highest scores for South African women, followed by Indian, French, Chinese and Japanese women. However, pairwise comparisons indicated significance only for Chinese versus South African ($p<0.01$), Japanese versus South African ($p<0.001$) and French versus South African women ($p<0.05$). No differences between ethnic groups were detected for wrinkle length ($H=4.66$, $p=0.32$) or volume ($H=7.95$, $p=0.09$).

TABLE 2 Descriptive statistics ($M \pm$ SD) for the skin image measures split by ethnic group.

	Chinese	Japanese	French	Indian	South African
Colour					
*L**	61.3 (3.1)	60.9 (2.8)	65.1 (2.7)	52.8 (4.0)	38.7 (5.9)
*a**	13.9 (1.5)	13.4 (1.5)	14.7 (1.3)	16.2 (0.9)	16.2 (1.8)
*b**	20.5 (2.5)	19.3 (2.5)	17.2 (2.4)	21.7 (1.7)	20.9 (2.6)
Gloss					
Contrast	5.93 (0.9)	6.3 (1.0)	5.4 (0.8)	8.1 (1.2)	12.1 (2.2)
Specular	68.0 (2.5)	67.8 (1.9)	68.7 (2.3)	61.4 (3.2)	51.2 (5.0)
Skin tone evenness					
Homogeneity	0.1 (0.005)	0.1 (0.004)	0.1 (0.005)	0.1 (0.004)	0.1 (0.004)
Contrast	314.2 (56.1)	293.1 (49.0)	277.5 (48.9)	616.4 (127.6)	674.0 (135.2)
Wrinkles					
Density	1.7 (1.4)	1.3 (1.1)	1.8 (1.7)	2.1 (1.9)	2.5 (1.5)
Length	546.5 (763.7)	507.3 (589.2)	570.3 (608.1)	639.9 (634.5)	562.5 (598.5)
Volume	1.26e5 (1.88e5)	1.11e5 (1.41e5)	1.27e5 (1.71e5)	1.49e5 (1.82e5)	1.96e5 (2.76e5)
Sagging					
Density	2.7 (2.6)	4.4 (3.8)	4.3 (4.3)	6.2 (3.9)	4.2 (3.2)
Length	426.9 (474.5)	830.7 (778.5)	536.0 (681.1)	976.2 (850.8)	769.4 (624.2)
Volume	1.24e5 (1.56e5)	1.95e5 (2.15e5)	1.73e5 (2.53e5)	3.08e5 (3.11e5)	2.29e5 (2.58e5)

Sagging

Facial sagging showed ethnic group differences for density ($H = 15.77$, $p > 0.01$), length ($H = 16.55$, $p < 0.01$) and volume ($H = 19.98$, $p < 0.001$). Density was highest for Indian women, followed by South African, Japanese, Chinese and French women. Post hoc tests showed significance for Chinese versus Indian ($p < 0.001$), Japanese versus Indian ($p < 0.05$), French versus Indian ($p < 0.05$) and South African versus Indian women ($p < 0.05$). The pattern was similar for length, with Indian women scoring highest, followed by South African, Japanese, French and Chinese women. Pairwise tests were significant except for Chinese versus French ($p = 0.68$), Japanese versus Indian ($p = 0.40$), Japanese versus South African ($p = 0.86$) and Indian versus South African women ($p = 0.50$). Volume was highest for Indian women, followed by South African, Japanese, French and Chinese women, with significance for Chinese versus Indian ($p < 0.001$), Chinese versus South African ($p < 0.001$), French versus Indian ($p < 0.01$) and French versus South African women ($p < 0.01$).

Associations between health ratings and technical measures

We performed multiple regressions (ordinary least square) on data from the total sample ($n = 180$), that is, all five ethnic groups together. Thus, age, health and attractiveness ratings were the dependent variables, respectively, and the technical measures ($k = 13$) were the independent variables ('predictors').

The model for age ratings ($F_{13,166} = 46.46$, $p < 0.001$, adjusted $R^2 = 0.77$) showed four predictors: wrinkling (density, length), sagging (length) and specular gloss (see Table 3). Age ratings were positively associated with wrinkling (density, length) and sagging (length) and negatively associated with specular gloss. Concerning health ratings, the regression model ($F_{13,166} = 19.41$, $p < 0.001$, adjusted $R^2 = 0.57$) showed three predictors: Contrast gloss, skin tone evenness (contrast) and wrinkling (density) (see Table 3). Health ratings were positively associated with contrast gloss and negatively associated with skin tone evenness (contrast) and wrinkle density. Attractiveness ratings were predicted by three technical measures ($F_{13,166} = 12.58$, $p < 0.001$, adjusted $R^2 = 0.46$). There were negative associations of attractiveness ratings with wrinkle density and sagging length; however, sagging volume showed a positive association with attractiveness ratings.

To further explore the possibility of differential predictors of face ratings across ethnic groups, we performed multiple regressions with the same set-up but this time separately for the ethnic groups. This led to the following five model results. Age: Chinese ($F_{13,22} = 16.49$, $p < 0.001$, adjusted $R^2 = 0.85$), Japanese ($F_{13,22} = 14.88$, $p < 0.001$, adjusted $R^2 = 0.84$), French ($F_{13,22} = 18.23$, $p < 0.001$, adjusted

$R^2=0.86$), Indian ($F_{13,22}=19.10$, $p<0.001$, adjusted $R^2=0.87$) and South African ($F_{13,22}=6.66$, $p<0.001$, adjusted $R^2=0.68$). The analysis revealed different predictors of age ratings, with measures of facial wrinkling and sagging identified in three of the five ethnic groups. Contrast gloss was a predictor of age ratings in Chinese women and colour *a** and *b** measurements predicted age ratings in French women (Table 4).

Health: Chinese ($F_{13,22}=5.41$, $p<0.001$, adjusted $R^2=0.62$), Japanese ($F_{13,22}=5.59$, $p<0.001$, adjusted $R^2=0.63$), French ($F_{13,22}=2.19$, $p=0.051$, adjusted $R^2=0.31$), Indian ($F_{13,22}=7.64$, $p<0.001$, adjusted $R^2=0.72$) and South African ($F_{13,22}=3.43$, $p<0.01$, adjusted $R^2=0.47$). Measures of facial wrinkle and sagging were the primary predictors of health ratings across ethnic groups. Colour *L** measurements predicted health ratings for Japanese women (Table 5).

Attractiveness: Chinese ($F_{13,22}=6.07$, $p<0.001$, adjusted $R^2=0.65$), Japanese ($F_{13,22}=1.91$, $p=0.087$, adjusted $R^2=0.25$), French ($F_{13,22}=4.46$, $p<0.01$, adjusted $R^2=0.56$), Indian ($F_{13,22}=5.73$, $p<0.001$, adjusted $R^2=0.64$) and South African ($F_{13,22}=5.36$, $p<0.001$, adjusted $R^2=0.62$). Facial wrinkling and sagging measurements predicted attractiveness ratings. No predictors emerged for the attractiveness ratings of Japanese women. Colour *b** measurements were an additional predictor of attractiveness ratings for South African women. (Table 6).

TABLE 3 Coefficient statistics for skin image measures significantly predicting age, attractiveness and health ratings in the multiple regression ($n=180$).

Variables	*B*	SE B	*β*	*t*	*p*
Age					
Specular gloss	−0.72	0.29	−0.41	−0.248	<0.05
Wrinkle (density)	3.16	0.68	0.39	4.65	<0.001
Wrinkle (length)	0.006	0.003	0.28	2.10	<0.05
Sagging (length)	0.007	0.002	0.42	3.20	<0.01
Health					
Contrast gloss	1.81	0.68	0.43	2.67	<0.01
Skin tone evenness (contrast)	−0.029	0.01	−0.40	−3.70	<0.05
Wrinkle (density)	−2.65	0.84	−0.36	−3.15	<0.01
Attractiveness					
Wrinkle (density)	−2.53	0.82	−0.39	−3.08	<0.01
Sagging (length)	−0.008	0.003	−0.55	−2.80	<0.01
Sagging (volume)	2.00e-5	0.000008	0.49	2.64	<0.01

TABLE 4 Coefficient statistics for skin image measures significantly predicting age ratings in the multiple regression split by ethnic groups ($n=36$ each).

Variables	*B*	SE B	*β*	*t*	*p*
Chinese					
Contrast gloss	3.85	1.68	0.33	2.29	<0.05
Sagging (length)	0.02	0.007	0.79	2.65	<0.05
Japanese					
Sagging (density)	−4.27	1.70	−1.17	−2.53	<0.05
Sagging (length)	0.03	0.008	1.70	4.04	<0.001
French					
*a**	−3.18	1.38	−0.29	−2.31	<0.05
*b**	−1.47	0.60	−0.23	−2.45	<0.05
Wrinkle (density)	6.66	2.11	0.76	3.16	<0.01
Sagging (density)	2.14	0.65	0.61	3.30	<0.01
Sagging (volume)	−6.27e-5	0.00002	−1.06	−2.80	<0.05
Indian					
Wrinkle (density)	4.02	1.26	0.62	3.19	<0.01
South African					
Wrinkle (length)	0.02	0.01	1.20	2.23	<0.05

TABLE 5 Coefficient statistics for skin image measures significantly predicting health ratings in the multiple regression split by ethnic groups ($n = 36$ each).

Variables	*B*	SE B	*β*	*t*	*p*
Chinese					
Sagging (length)	−0.02	0.008	−0.978	−2.06	0.05
Japanese					
*L**	−2.82	1.26	−0.93	−2.23	<0.05
Specular gloss	2.66	1.14	0.58	2.34	<0.05
Sagging (density)	3.65	1.57	1.63	2.23	<0.05
Sagging (length)	−0.02	0.007	−2.05	−3.23	<0.01
French					
Wrinkle (density)	−8.48	3.68	−1.25	−2.31	<0.05
Indian					
Wrinkle (density)	−3.71	1.73	−0.62	−2.14	<0.05
South African					
Wrinkle (length)	−0.03	0.01	−0.56	−0.69	<0.05
Wrinkle (volume)	5.45e-5	0.00002	1.43	2.33	<0.05

TABLE 6 Coefficient statistics for skin image measures significantly predicting attractiveness ratings in the multiple regression split by ethnic groups ($n = 36$ each).

Variables	*B*	SE B	*β*	*t*	*p*
Chinese					
Sagging (length)	−0.02	0.009	−0.96	−2.12	<0.05
Japanese					
N/A	—	—	—	—	n.s.
French					
Wrinkle (density)	−11.91	3.48	−1.48	−3.42	<0.05
Indian					
Wrinkle (density)	−3.41	1.63	−0.68	−2.10	<0.05
South African					
*b**	2.24	1.01	0.63	2.21	<0.05
Wrinkle (length)	−0.02	0.009	−1.27	−2.18	<0.05
Wrinkle (volume)	3.69e-5	0.00002	1.11	2.11	<0.05

DISCUSSION

In this study, we found ethnic differences in assessments of (mean) health (but not age or attractiveness) of female faces made by naïve raters (Table 1). Skin image analysis revealed differences between ethnic groups, including in facial skin colour, gloss, tone evenness, wrinkling and sagging. In analyses of the total sample (i.e. all five ethnic groups) to investigate relationships between face ratings and skin image measurements, we identified differential predictors of age, health and attractiveness. Differences in the relative contributions of individual skin features to predictions of age, health and attractiveness ratings also were observed between ethnic groups. Facial wrinkling and sagging were the best predictors of face ratings in each ethnic group, with some differences in the type (or predictive magnitude) of skin features. Collectively, the findings corroborated reports of differences between ethnic groups in female facial skin (assessed by digital image analysis). In addition, the findings indicate differential effects of skin features on ratings of female age, health and attractiveness, within and between ethnic groups.

The observed ethnic differences are not readily attributable to 'colourism' [35], as women's faces were rated by members of their own ethnicity. Thus, effects like those observed in Voegeli et al. [14], in which Indian assessors judged South African women particularly low for health and attractiveness, cannot account for the lower health assessments of Indian and South African women in this research. Cultural variation in standards of self-criticism could have contributed to the observed ethnic differences in health ratings [54, 55]. An alternative or additional explanation is that lower health ratings of Indian and South African women are caused by greater skin discolouration (among other skin features). The skin image analysis indicated higher scores of contrast gloss, skin contrast and wrinkling/sagging for Indian and South African women compared with women from other ethnic groups (Table 2). Although research indicates an earlier onset and greater skin wrinkling/sagging in lightly pigmented Caucasian skin than in other skin types, pigmentary problems coincident with higher UV exposure may be more common in Indian and South African women despite greater melanin in darkly pigmented skin (see [37] for review). Previous research in lightly pigmented British [20, 22] and French [56] women suggests that the age-related increase in facial discolouration (i.e. decrease in skin tone evenness) affects perceptions of health. Individuals are sensitive to changes in skin colour evenness independent of familiarity with skin variation in a given population and facial identity [57], suggesting that discolouration is universally associated with less positive judgement [58].

We observed ethnic differences in CIELAB measurements of women's skin colour [45], corroborating previous research (e.g. [59, 60]). Higher L^* (lightness) and lower a^* (redness) values were observed in Chinese, Japanese and French women than in Indian and South African women. Ethnic differences in b^* (yellowness) values were lowest in French women and showed less variation across ethnic groups than L^* and a^* values. Consistent with this finding, Xiao et al. [59] reported overlap in the distributions of $L^*a^*b^*$ measurements across four ethnic groups (Caucasian, Chinese, Kurdish and Thai), with Thai skin exhibiting the highest and Caucasian skin exhibiting the lowest b^* values. These authors conclude that individual differences in lightness and yellowness are primarily attributable to ethnicity, whereas redness shows higher variation across different body locations than across different ethnic groups. This study focuses on facial skin features and their relationships with face ratings; therefore, the differences between ethnic groups, particularly for a^* and b^* values, are small compared to differences in skin lightness (L^*) and should be interpreted with caution. In addition, luminance contrast (i.e. the colour and luminance differences between facial features and the surrounding skin) correlates positively with age, health and attractiveness assessments of female faces [61–63]. Considering facial contrast in cross-cultural research may reveal more robust results regarding the role of colour measurements, affording greater clarity in regional CIELAB differences in the faces of different ethnic groups and their effects on perception.

This study identified ethnic differences in facial wrinkling and sagging—these features were more pronounced in Japanese and Indian women (sagging) and in South African women (wrinkling). Previous research indicates ethnic variation in the age-related increase in facial wrinkling/sagging due to intrinsic factors and extrinsic factors [37, 64, 65]. Asian skin and Black African skin are characterized by more compact dermis than Caucasian skin, which may contribute to a lower incidence of facial rhytides among Asian and Black African women [66–69]. In addition to skin structural differences, the biological explanation for differences in skin variables may be related to inflammatory processes responding to differential exposome exposures or intrinsic proinflammatory signalling differences. We note, however, that knowledge of skin ageing exposome factors is limited [70–73]. Digital skin image analysis in this study indicated a difference in wrinkle density for South African women versus Chinese, Japanese and French (but not Indian) women, but no ethnic differences in wrinkle length or volume. Indian women displayed the largest facial sagging scores for density, length and volume. Hence, our findings suggest larger ethnic differences for facial sagging than for wrinkling in terms of Caucasian versus Asian/Black African skin.

In addition to assessments of ethnic differences in age-related facial skin features using image analysis, this study examined associations of these features with naïve assessors' (women and men) ratings of age, health and attractiveness. In the total sample ($n=180$), perceived age was negatively associated with specular gloss and positively associated with wrinkles (both density and length) and sagging (length). These results suggest that changes in facial skin surface topography are key features affecting age perception [14, 15, 74, 75]. The negative associations between specular gloss and age ratings corroborate previous reports indicating lower glow/radiance with increasing age [76]. Facial wrinkling (i.e. density) also was negatively associated with health ratings. Contrast gloss (positive) and skin tone contrast (negative) were associated with health assessments from faces. These findings suggest that skin colouration may be more influential in health assessments than skin surface topography cues [18, 20, 76–78]. Previous research showed that the contrast between skin surface reflection and darkness of the subsurface reflection (i.e. skin tone) is positively associated with skin gloss perception [79]. Humans are sensitive to changes in gloss [80]. Studies show an increase in perceived gloss after anti-ageing treatment [81] and positive associations of perceived gloss with ratings of facial attractiveness [34, 82]. This study found associations between skin surface topography (but not skin colouration/gloss) with attractiveness ratings. Perceived age (negatively) and health (positively) are associated with perceptions of attractiveness. Research on Caucasian women suggests greater contributions of perceived age than of perceived health to attractiveness assessments [20]. Whether this finding generalizes to other ethnic groups is unclear, although this study provides preliminary evidence that this is the case from analyses performed separately for the ethnic groups ($n=36$ each).

Analyses considering the ethnic groups individually produced similarities with and differences from results generated from analyses that included the total sample. A general finding regards associations between age ratings and facial wrinkling and sagging (Table 4). Two observations are noteworthy. First, for French women CIELAB *a** and *b** scores were negatively associated with age ratings (in addition to facial wrinkling/sagging) and, for Chinese women, contrast gloss was positively associated with perceived age. These results may reflect ethnic differences in the weighting of skin features in age assessments, with colour playing a role, particularly in Caucasian faces (see Flament et al. [33]). Second, the explained variance (R^2) in age ratings was high for the regression model in each ethnic group (although lower for South African women than for other ethnic groups), which suggests that, across ethnic groups, facial wrinkling/sagging is the predominant determinant of age perception. We note that differences between the ethnic groups in the predictors of age perception (and face ratings, in general) should be interpreted with caution, given the sample size of rated women ($n = 36$) in each ethnic group. In addition, multiple regressions can be conducted defensibly in several ways (e.g. forward, backward and mixed), and the inclusion/exclusion of independent predictors of face ratings can produce differing results. We decided against a sequential regression procedure and report the (significant) coefficients produced by entering all independent variables (i.e. skin features) in a single step. This can sometimes lead to the identification of spurious relationships in a model but has the advantage that the procedure is more robust to data mining criticism [83].

As for age ratings, the regression models that predicted assessments of health in ethnic groups suggested a large role for skin surface topography features (i.e. winkling/sagging) (Table 5). An interesting observation was that *L** (negative) and specular gloss (positive) are additional predictors of health assessments for Japanese women. This suggests that lower lightness and higher gloss (radiance) are positively associated with health perception. Pale skin in Japanese women has been reported for centuries to be preferred and a plethora of products offer skin whitening, typically by reducing (or halting) melanin production [84]. Perhaps, this finding reflects the conflation of different beauty standards, which may happen when East Asian beauty 'ideals' encounter Western consumer culture. This is, of course, speculation, and there may be additional or alternative explanations for the observed relationships.

The effects of skin features (wrinkling/sagging, in particular) on health ratings were lower than on age ratings. In French women, for example, the regression model failed to reach statistical significance (although wrinkle density was negatively associated with health ratings). Therefore, we consider the identified relationships of skin features to health assessments to be less robust than for age assessments. Another problem in the interpretation of the relative contributions of skin features to perception concerns the modelling of interaction effects. The regression models assume linear effects on the dependent variable (i.e. ratings) which may not always be the case. Also, considering interactions among independent variables (i.e. skin features) would have led to model overfitting. The limitations of traditional statistical analyses may warrant consideration of recent developments in face research (i.e. 'deep' models [85] for application to the cosmetic sciences [86]).

The regression analyses of attractiveness ratings split by ethnic group identified fewer predictors and a non-significant model (and coefficient) for Japanese women (Table 6). Nevertheless, facial wrinkling/sagging again was the primary (nominal) predictor of attractiveness ratings. For South African women, *b** (yellowness) was positively associated with attractiveness and wrinkle volume (i.e. the same as with health ratings). The latter finding may appear counterintuitive; here, it is important to consider the different properties of a wrinkle, namely its length and volume. In South African women, wrinkle length was negatively associated with health and attractiveness ratings. Thus, the summed length of all wrinkles correlated negatively with perceived health and attractiveness. Wrinkle volume, in contrast, is indicative of the depth of a wrinkle and less dependent on the occurrence frequency. It may be that 'growing older gracefully' by displaying certain age-related skin signs was of less import for South African assessors. The (age-corresponding) presence of wrinkle volume may be more socially accepted by South Africans than by residents of other cultures represented in this research.

CONCLUSION

The findings of this study suggest ethnic differences in female facial skin features (as assessed by skin image analysis) and differential associations of these features with naïve raters' assessments of age, health and attractiveness within and between ethnic groups. Facial wrinkling and sagging were the best predictors of age and attractiveness ratings, and skin tone evenness and gloss had an additional role in ratings of health (Figure 3).

Limitations due to sample sizes (and thus to statistical power), the observed ethnic differences in the type or magnitude of associations between skin features and face ratings should be considered preliminary and require

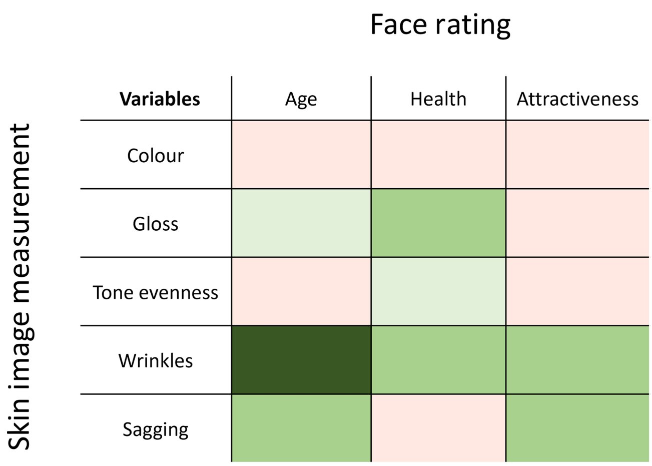

FIGURE 3 Graphical summary of effects in the total sample (five ethnic groups together; $n=180$). Green colours indicate an effect of at least one skin image analysis variable corresponding to that feature on face assessment (dark green $p<0.001$, medium green $p<0.01$ and light green $p<0.05$). Red colours indicate no statistically significant effect was detected.

replication before more definitive conclusions are made. This includes possible ethnic differences in the assessment (positive vs negative) of skin ageing signs due to cultural values and traditions. Moreover, we have not taken into account product type or usage conditions and the relative exposome influences in the different geographical locations. Understanding ethnic variation in attitudes towards ageing and healthy/attractive appearance, together with objective (i.e. quantifiable) descriptions of individual and group-specific differences in skin features are important for the formulation of targeted solutions to effectively address the consumer's concerns with facial signs of ageing.

ACKNOWLEDGEMENTS

The authors thank the study volunteers who participated in the study, Elodie Prestat-Marquis and Marie Cherel (Newtone Technologies, Lyon, France) for their support in preparing, conducting and analysing this study and Rotraut Schoop (DSM Nutritional Products, Kaiseraugst, Switzerland) for statistical advice. They further thank the study directors for their indefatigability in conducting the study at the following centres, Etienne Camel and Mathilde De Torsiac at IEC, Lyon, France; Yumiko Seki at IEC Tokyo, Japan; Manoj Choudhry at IEC Cape Town, South Africa; Peggy Ruan at IEC Guangzhou, China and Rashi Nangia and Rajat Gupta at CIDP Biotech, New Delhi, India.

FUNDING INFORMATION

All funding was provided by DSM Nutritional Products, Basel, Switzerland.

CONFLICT OF INTEREST STATEMENT

RV and RC are employees of DSM, BF and AVR are consultants to DSM and RB is an employee of Newtone Technologies. TKS states no conflict of interest.

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How to cite this article: Voegeli R, Campiche R, Biassin R, Rawlings AV, Shackelford TK, Fink B. Predictors of female age, health and attractiveness perception from skin feature analysis of digital portraits in five ethnic groups. Int J Cosmet Sci. 2023;45:672–687. https://doi.org/10.1111/ics.12877