Modeling the Relation between Skin Attractiveness and Physical Characteristics*

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ABSTRACT

There is a wide range of requirements for representing skin quality in various fields, such as computer graphics and cosmetics. However, accurate representation of skin quality is a difficult technical issue, because of the complex physical characteristics of skin and its constituent substances and structure. The objective of this study is to clarify the latent factors in the impression of skin, mainly skin attractiveness and to provide systematic modeling of the relation between impression and physical characteristics. This will not only enable intuitive representation of skin quality, but will also help elucidate the human recognition mechanism in relation to skin. To build the model, we first select words from those that are generally used to assess skin. Next, we study techniques capable of accurate skin representation, based on the physical characteristics of skin, and create CG images of skin. We then use the words and images to clarify the latent factors for forming a visual impression of skin. Finally, we conduct a regression analysis on the results obtained in the subjective evaluation test to build a systematic model to estimate the impression evoked, based on the skin's physical characteristics. This makes it possible to estimate impressions from physical characteristics and conversely, to estimate those specific physical characteristics that contribute to a desired impression.

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CCS CONCEPTS

• **Computing methodologies → Computer graphics → Graphics systems and interfaces → Perception**

KEYWORDS

Skin attractiveness, prediction model, biophysically-based model, subjective evaluation test

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1 INTRODUCTION

Humans are intimately aware of faces and skin quality, using them clues to estimate age, gender, health, and emotions [1]. It is also an important field of study from both academic and practical perspectives. Thus, it is a matter of great interest to us.

Realistic representation of skin quality is widely sought after in fields such as computer graphics (CG) and cosmetics. However, because skin quality is determined by complex physical factors, including pigments (e.g., melanin and hemoglobin) and multi-layered surface structures and microstructures, accurate texture are a difficult technical problem.

Our objectives are to clarify the latent factors of skin impression and to provide systematic modeling of the relation between impression and physical characteristics. This model will make it possible to estimate the physical features contributing to skin impression and will enable intuitive rendering of skin quality. This promises to simplify skin quality representation and to help elucidate the human recognition mechanism, in relation to skin. Furthermore, it has potential for industrial application, such as cosmetics development, which also creates positive impressions of skin.

To create a prediction model for skin quality that systemizes the relation between impression and physical characteristics, we first select words (i.e., evaluation terms) from those generally used to assess skin quality. We look for words that are suitable for skin evaluation. Then, we study techniques capable of accurate skin representation, based on its physical characteristics. Then, we create CG images of the skin. The acquisition of a high-accuracy model requires that CG images be both comprehensive and representative. Using the selected evaluation terms and CG images, a subjective evaluation test is conducted. By conducting a factor analysis of the obtained results, the latent factors, forming a visual impression of skin, are clarified. Lastly, modeling is performed through a regression analysis of the relation between impression factors and physical characteristics. Thus, we realize a technique for estimating impression from physical characteristics. Conversely, we realize a technique for estimating the physical quantity contributing to the desired impressions.

2 PRIOR RESEARCH

The visual impression of skin can be divided into two areas: impressions from mesoscale shape characteristics, such as wrinkles or pores and those from microscale physical characteristics, such as melanin and hemoglobin, affecting optical characteristics. In studies of the skin's mesoscale shape characteristics, Igarashi *et al.* proposed an eigenspace filtering technique to generate images with suppressed mesoscale shape characteristics for application in cosmetics development, and they reported on its usefulness [2]. Furthermore, Arakawa *et al.* proposed a new non-linear filtering technique and achieved wrinkle and spot elimination on facial images [3]. However, because mesoscale shape characteristics evoke a negative impression of the skin, in most cases, these studies did not report on the importance of impression. Therefore, for utility, our study will not look at mesoscale shape characteristics.

In studies of the effects of microscale physical characteristics of skin, studies have reported that blood circulation, melanin, and beta-carotene impact healthy appearance [4,5]. Other studies examined types of physical skin characteristic impressions, such as "translucent feel," "dewy feel," and "shininess" [6-8]. Many studies clarified the physical characteristics required to achieve "pearly skin." [9,10] However, most of those studies focused on brightness distribution in skin images, or they modeled the relation between $L^*a^*b^*$ value variation and impression. Few studies clarified the correlation between impression and variation in concrete physical quantities of melanin or hemoglobin. Moreover, no studies, to date, have clarified the overall make-up of skin impression, nor have they proposed systematic models expressing correlation with physical characteristics.

Our objective is to systematically model the relation between skin impression and its microscale physical characteristics. To this end, for evaluation terms, we use words that are suitable for representing skin quality and impression. These words are collected and selected through a practical experiment. Moreover, we conduct a psychological experiment and perform statistical processing, using CG images chose for specific physical quantities of melanin and hemoglobin.

3 SELECTION OF SKIN EVALUATION TERMS

To model the relation between the visual impression of skin and its physical characteristics, we conduct a subjective evaluation test of skin images and examine the correlation with the physical features of the skin in images. To adequately ascertain the make-up of skin impression, words that are comprehensive and representative (i.e., evaluation terms) are selected from words generally used to describe skin states. In this research, we selected evaluation terms through some tests with statistical validity.

Table 1: Representative Terms (Low-order impression)

Cluster 1		Cluster 4	
Evaluation term / distance from centroid		Evaluation term / distance from centroid	
florid	0.047	serene	0.214
lively	0.047	calm	0.281
young	0.049	grown-up	0.370
Cluster 2		**Cluster 5**	
Evaluation term / distance from centroid		Evaluation term / distance from centroid	
clear	0.040	tired	0.142
beautiful	0.042	unhealthy	0.200
neat and clean	0.112	lackluster	0.222
Cluster 3			
Evaluation term / distance from centroid			
unassuming	0.076		
natural	0.103		
general	0.160		

Table 2: Representative Terms (High-order impression)

Cluster 1		Cluster 5	
Evaluation term / distance from centroid		Evaluation term / distance from centroid	
moist	0.030	dry	0.058
sticky	0.031	little moisture	0.075
supple	0.039	smooth and shiny	0.084
Cluster 2		**Cluster 6**	
Evaluation term / distance from centroid		Evaluation term / distance from centroid	
dewy	0.033	firm	0.109
radiant	0.045	dull	0.136
translucent	0.061	uneven-colored	0.159
Cluster 3		**Cluster 7**	
Evaluation term / distance from centroid		Evaluation term / distance from centroid	
smooth and dry	0.181	puffy	0.396
even-colored	0.251	thick	0.405
white	0.262	yellow	0.502
Cluster 4			
Evaluation term / distance from centroid			
greasy	0.063		
oily	0.100		
heavy	0.126		

Furthermore, based on the findings by Nagai *et al.*, the cognitive process for material texture is structured in a hierarchical manner [11]. Thus, we categorized selected evaluation terms, by mutual consent, into "low-order evaluation terms," evaluating the skin's physical characteristics, and "high-order evaluation terms," evaluating the emotion evoked by the skin's quality.

Moreover, by applying cluster analysis, representative evaluation terms (i.e., representative words) used in the subjective evaluation test. The representative words for low-order and high-order impressions are listed in Tables 1 and 2, respectively.

4 CREATION OF CG IMAGES BASED ON SKIN'S PHYSICAL CHARACTERISTICS

The systemization of the relation between skin's physical characteristics and impression requires us to conduct a subjective evaluation experiment for skin images and to study the correlation with the physical features of the skin in those images. Accordingly, when using photographs of skin as stimuli, the physical features of the skin must be measured each time. However, accurate measuring of physical features, such as the amount of melanin, hemoglobin, or layer thickness, is extremely difficult. Moreover, because physical features cannot be controlled when using photographs as stimuli, there is an issue regarding the comprehensiveness of the experimental stimuli. We solve this by creating CG images of skin, instead of photographs, for experimental stimuli. Their physical features are controlled.

This section describes the technique to create CG, based on skin's physical characteristics, and the physical features of skin to control when creating image stimuli.

4.1 Creation method of CG images as experimental stimuli

Because accurate quality representation is required for our study, we employed the biophysically-based model created by Iglesias-Guitian *et al.*, performing simulation based on the skin's physical features [12]. This technique allows the calculation of parameters needed for skin-rendering, including absorption and scattering coefficients and layer thickness, based on the skin's thickness and pigmentation. These are common parameters in the fields of medicine and biophysics. Furthermore, the introduction of data on skin thickness and pigmentation by age enables us to represent changes in optical characteristics of the skin with ageing.

4.2 Physical features of skin

In terms of physical features that affect skin quality, we focus on changes in melanin and hemoglobin content. These are microscale physical features having evident visual effect. It varies based on changes of skin thickness and micro-surface unevenness substantially smaller than mesoscale shapes (i.e., a few mm). This section describes each physical feature required for rendering the experimental stimuli.

4.2.1 Melanin. Melanin is the pigment that affects the darkness of skin. The differences in skin color between black, white, and Asian people are determined by their melanin concentration and by the ratio of eumelanin and pheomelanin in relation to the amount of melanin. To reveal the difference in impression caused by changes in the amount of melanin, we create experimental stimuli by increasing the amount of melanin in five steps of 9 %, from 0 – 36 %. For the ratio of eumelanin and pheomelanin, we use data on the skin of Asian people [13], as measured by Hennesy *et al.* To exclude the effects of suntans in the creation of the experimental stimuli, we use pre-suntan measured averages of eumelanin 94 % and pheomelanin 6 %.

4.2.1 Hemoglobin. Hemoglobin exists copiously in blood, and is the main pigment accounting for the redness of the skin. To reveal the changes of impression with the changes in hemoglobin, experimental stimuli images are created by increasing hemoglobin in five steps of 5 %, from 0.1 – 20.1 %. Furthermore, based on the ratio of blood flowing through the arteries and veins, we set the ratio oxygenated hemoglobin to 64 % and deoxygenated hemoglobin to 36 %.

4.2.3 Bilirubin. Bilirubin is a green pigment produced by metabolizing hemoglobin. Normal values of bilirubin are 0.009 – 0.019 g/l, and, if exceeding 0.025 g/l, it is recognized as jaundice. The present study sets the amount of bilirubin at the center of the normal range, 0.014 g/l.

Absorption coefficients for each spectrum in the layers of the skin used for rendering are determined by the amount of these skin pigments. Therefore, it is chiefly represented as skin color data in the rendered CG images.

4.2.4 Shape properties. In the present study, shape properties of the skin are defined as the height of microsurface unevenness, *Rz*, and thickness of each skin layer, *d*. Because these parameters determine shape properties uniquely specified by age [12,14], values are used for the experimental stimuli images for the ages of 30, 55, and 80. The parameters used for rendering are listed in Table 3.

Table 3: Shape property parameters

Shape properties	*d* (mm)					*Rz* (nm)
	coreum	epderm	papillary dermis	layerreticular	hypodermis	
30	0.02	0.08	0.18	1.82	5.90	78.4
55	0.02	0.07	0.13	1.36	1.65	104.1
80	0.02	0.06	0.11	1.14	0.76	151.3

4.3 Rendering results

Using the technique and parameters described in the previous section, 75 types of skin images are rendered (5 grades of melanin x 5 grades of hemoglobin x 3 grades of shape properties). For the skin model, a model created using 3D data [15] is used, and the renderer is the physically-based PBRT [16]. Because changes in appearance of an object via changes in the direction of observation is believed to be an important factor in

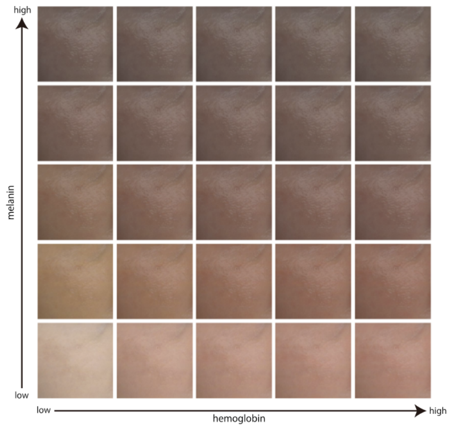


Figure 1: Changes in skin quality through changes in amounts of melanin and hemoglobin (shape properties: 30 years)

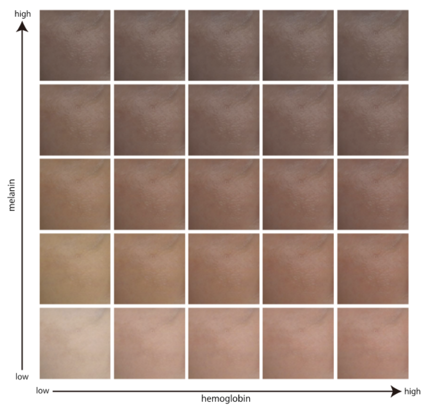


Figure 2: Changes in skin quality through changes in amounts of melanin and hemoglobin (shape properties: 55 years)

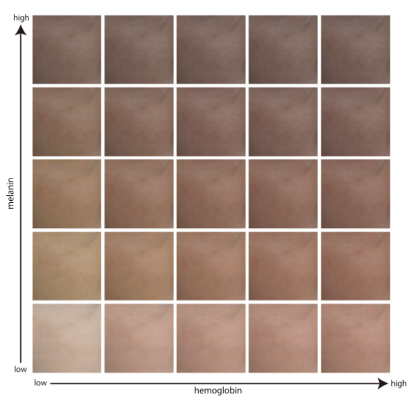


Figure 3: Changes in skin quality through changes in amounts of melanin and hemoglobin (shape properties: 80 years)

the recognition of skin quality [17], participants in the subjective evaluation experiment are not shown single still images. They are instead shown a series of images from different observation angles. The frontal direction of this model data is taken as the standard, and by rotating the viewpoint (i.e., camera position) around the vertical axis at 5° intervals between -10° and +10°. Five skin CG images are obtained, each from a different viewing angle. They are taken as one image series set. For stimuli, all images are shown for 0.5 s in the following order: 10°, -5°, ±0°, +5°, +1-°, ±0°, and -5°. Furthermore, to exclude the impact on facial features impression, images are trimmed to 300 x 300 pixel-sized squares of just the cheek alone. Fig. 1, 2, and 3 show the 75 images used in the experiment.

5. SUBJECTIVE EVALUATION EXPERIMENT

This section describes the subjective evaluation experiment that used CG skin images rendered from skin's physical features as experimental stimuli and their selected evaluation terms.

5.1 Participants

Participants in this experiment were 10 university students (6 males, 4 females) in their 20s, considered to be of an age group that spends more money on beauty products and services than elderly generations and to have a high level of interest in skin.

5.2 Experimental environment

Experimental stimuli comprised 75 types of image series sets, shown on a monitor one type at a time. The background color was set to 18 % gray. The experiment was conducted in a dark room, and the monitor was color-calibrated for each test. The image sets were repeated until responses were complete.

5.3 Experimental procedure

Participants graded each representative term in relation to each stimulus on a scale of 1 to 7: 1, applies very much; 2, applies; 3, applies somewhat; 4, cannot say either way; 5, applies little; 6, does not apply; and 7, does not apply at all. Additionally, participants were instructed to assess their intuitive impression of the images they were shown during the experiment.

5.4 Results

A factor analysis using the maximum likelihood method and promax rotation was applied to the averages for each evaluation item in the 10 subjects' obtained data. To determine the number of factors, the reference was set at an eigenvalue of 1 or higher. The factor analysis resulted at the third factor for low-order impression with cumulative contribution ratio of 74.054 % and eigenvalue, 1.474. For high-order impression, up to the third factor was extracted. However, because commonality for "grown-up" was close to 0, the term "grown-up" was excluded. A factor analysis was then applied to the 14 remaining terms. The results were a cumulative contribution ratio of 78.882 % up to the second factor and an eigenvalue of 1.06.

5.5 Discussion

For low-order impression, high-loading factors were indicated for the first factor with representative terms, such as "greasy," "oily," and "heavy," for the second factor with representative terms, such as "white," "translucent," and "radiant." For the third factor, representative terms, such as "moist" and "dewy," were indicated. Accordingly, the first factor was taken as the impression in relation to fat of the skin (i.e., sticky feel); the second factor was taken as the impression in relation to translucency (i.e., translucent feel); and the third factor was taken as the impression in relation to the amount to moisture in the skin (i.e., moist feel"). For high-order impression, high loading factors were indicated for the first factor with representative terms, such as "neat and clean," "beautiful," and "clear." For the second factor with representative terms as "florid" and "lively" were indicated. Thus the first factor was set as "beautiful feel," and the second was set as "vital feel."

6. MODELING THE RELATION BETWEEN SKIN IMPRESSION AND PHYSICAL CHARACTERISTICS

To reveal the relation between physical characteristics and impression factors obtained in the previous section, we performed a regression analysis on the amount of melanin, the amount of hemoglobin, and the physical characteristics in the stimuli images used for impression evaluation as predictor variables and the factor scores of high-order impression factors as objective variables (2 layer model). Regression analysis was also performed with the physical characteristics as predictor variables, scores of low-order impression factors as objective variables and scores of low-order impression as predictor variables, scores of high-order impression factors as objective variables (3 layer model). A prediction model was then built to estimate high-order impression factors through low-order impression factors, from the skin's physical features.

6.1 Method

Using a stepwise method with a reference value, F, a multiple regression analysis was performed. We inserted variables with F lower than 0.5. A variance inflation factor of 10 or lower was indicated for all variables in this analysis. Multi-collinearity between variables could not be confirmed.
Both "beautiful feel" and "vital feel" can be estimated with a good degree of accuracy from the coefficients of determination. The systematic model of impression and physical characteristics based on these results is shown in Fig. 4, and adjusted R-squared in each model is shown in Table 4.

Table 4: Adjusted R-squared in the systematic models

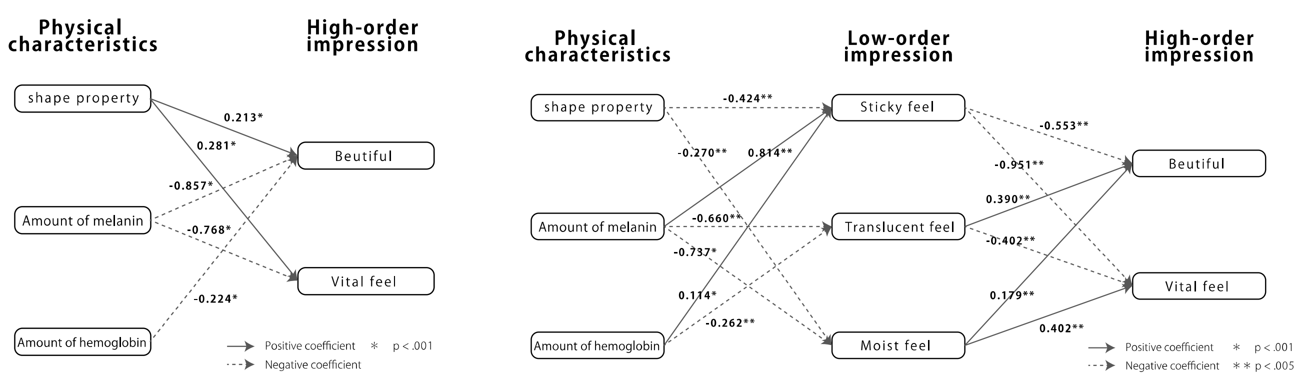
	adjusted R-squared	
	2 layer model	3 layer model
Beautiful	0.828	0.823
Vital feel	0.665	0.665

6.2 Discussion

6.2.1 Low-order impression. the results of the multiple regression analysis confirmed that "sticky feel" was explained by the three physical characteristics of shape characteristics, amount of melanin, and amount of hemoglobin. Because the shape characteristic coefficient has a positive value and the amount of melanin and hemoglobin have negative values, the darker the skin color and the stronger the specular reflection component, the stronger the sensation of "sticky feel." This may be because the specular reflection component is felt to be more prominent when the skin gets darker. Thus, the amount of fat in the skin surface feels higher.

The translucent feel is explained by the physical features of melanin and hemoglobin amounts. Because coefficients for melanin and hemoglobin are both negative values, the translucent feel increases as the amount of pigment decreases. These results show that skin's translucent feel is determined by texture and moisture in each layer and the amount of melanin and hemoglobin. These results are like those of prior research [6], which found that the amount of light absorbed in the skin decreases as the amount of melanin and hemoglobin decreases. Hence, the translucent feel increases. This suggests validity.

Lastly, the moist feel is explained by the two physical characteristics of shape and the amount of melanin. The fact that values are negative, both for the shape characteristics and the melanin coefficients, as specular reflection gets stronger and the amount of melanin in the skin decreases, the "moist feel" gets stronger. Thus, the skin's translucent feel is strongly affected by the rate of light absorption, whereas, for moist feel, the specular



(a) 2 layer model (b) 3 layer model

Figure 4: Estimation of high-order impression through low-order impression from physical characteristics

reflection component has an impact. Furthermore, based on a comparison of the results for "sticky feel" and "moist feel," these are judged to be because there are oily components where the amount of skin pigment is high. Conversely, they can be caused by moisture where the amount of skin pigment is low.

6.2.2 High-order impression. The prediction model for estimation of high-order impressions, based on low-order impressions, revealed that the "beautiful feel" is explained by "sticky feel," "translucent feel" and "moist feel." Based on the negative value for the "sticky" feel coefficient and the positive values for "beautiful" and "moist" feel coefficients, skin that is not sticky but is translucent and moist has a strong feel of "beauty." Because coefficients are higher for translucent feel than for moist feel, "translucent feel" plays a stronger role in the perception of beauty. Moreover, looking at beauty in terms of physical characteristics, values were negative for melanin and hemoglobin coefficients, but positive for the shape characteristics coefficient. "Vital feel" is explained by the same three low-order impressions as "beautiful." Because values are negative for the "sticky" and "translucent" coefficients and positive for "sticky," skin with a little "sticky" and "translucent" and a high-level "moist," had a strong "vital feel."

7. CONCLUSION

We performed systematic modeling of the relation between the physical characteristics of skin and the visual impression that these provided. Firstly, representative terms having a high degree of comprehensiveness and representativeness for the evaluation of skin were selected from generally used terms. Next, CG skin images were created using a technique capable of accurately representing skin quality, based on skin's physical characteristics. Then, using the selected representative terms and the CG skin images, a subjective evaluation experiment was performed with male and female subjects in their 20s, revealing the make-up of skin impression in the age group highly interested in skin. Lastly, a regression analysis was performed with factor scores obtained in the subjective evaluation experiment as objective variables and physical characteristics as predictor variables, to build a model to estimate the impression, based on skin's physical characteristics. Thus, its statistical validity was confirmed. The findings were then discussed.

Future issues include the creation of a systematic model that accounts for pigments other than those of the present study. Furthermore, this study only dealt with microscale physical characteristics, but because mesoscale physical characteristics, such as wrinkles and pores, are an important factor in actual skin, a model needs to be built that includes these characteristics. Apart from this expansion of physical characteristics, we also want to conduct a subjective evaluation with subjects from a wider range of age groups to ascertain generational differences in the make-up of skin impression. This requires further study of more statistically suitable techniques for evaluation term recruitment standards.

We further aim to realize a system to generate skin images with exaggerated impression factors, based on the systematic model obtained in this study.

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