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The Correlation Between Blood Oxygenation Effects and Human Emotion Towards Facial Skin Colour of Virtual Human

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Abstract The quest for determining the glamorous conditions of the human facial skin based on the texture, color, health perception, races, age and charm is never-ending. Manifestation of facial skin is subjected to the physical and physiological state of human emotions. The facial expression and appearance alters as we move, talk, think and endure stress under constant flux. The colors of skin is one of the key indicators of these changes and the color resolution is decided by the scattering and absorption of light within the skin layers containing chromophores in the melanin and hemoglobin oxygenation in the blood. Understanding the facial color distribution, homogeneity of the pigmentation or skin quality under stimuli are the key issues. We examine the correlation between blood oxygenation in changing facial skin color and basic natural emotional expressions such as angry, happy, sad and fear using the Pulse Oximetry and 3D skin analyzer. The data from seven subjects with three female of age 17, 25 and 35 years, four male of 22, 30, 36, 40 years under different number of partially extreme facial expressions are feed in the new dynamic model for simulation. Experimental results are analyzed to establish a direct relationship between human emotion and facial oxygenation. The strong emotion such as anger is found to stimulate more oxygen under facial skin transforming the face red or rosiness. Furthermore, other emotions assisted with less oxygen concentration create the skin pallor or whitish. Our results in perceiving the human emotions based on facial skin color may contribute towards the development of human aided virtual reality and game environment.

Keywords Facial skin color · Blood oxygenation · Emotion · Pallor · Skin analysis · Facial expression · Virtual reality and game environment

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1 Introduction

Face of human is perhaps the most important art object and central aspect of phenotype that plays a significant role in the interactions with the mate choice [1, 52]. The proportions and expressions of the human face are

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important to identify origin, emotional tendencies, health qualities and often fundamental to human social interaction. Many different types of important information are visible in faces. The facial recognition is one of many innate reflexive cognitive competencies. Body or ornament color reflects underlying physiology in several species. Moreover, these color signs are perceived by conspecifics and used as social and sexual signals. The human faces are intensively studied to determine their impact on the health perceptions, attractiveness, emotions, species, age and shapes [2, 3]. Majority of the studies on the skin color and texture contribute towards the apparent facial health and attractiveness without establishing any correlation effects [4–8, 53]. The mechanism behind the appearance of facial colors and their influences on emotional expressions are far from being understood. It is reported that the homogeneity and distribution of human facial skin color contributes to health perceptions, age and allure [4, 5, 7, 54]. Fink et al. [4] recognized that the rating of the facial glamour is connected to the skin color homogeneity. Specifically, more homogeneous the color distribution, more attractive the human face appears. Extra homogeneous chromophores (melanin and hemoglobin) distribution in the skin relates positively to the health, allure and freshness [7, 55]. Meanwhile, the facial color of younger women is perceived to be charming, youthful, healthier and more attractive than their old counterpart because of the color distribution [5, 56]. Furthermore, the enhancement in female allure is related to the increase in contrast between the luminance of the facial features and the rest of the facial skin but the same effect reduces the masculinity charm in male faces [9]. Jones et al. [6] asserted that the health ratings of facial skin patches is related to the entire allure. In fact, the skin color and texture continue to contribute to the facial attractiveness even if the coloration over the whole face cannot be viewed. Stephen et al. [8] investigated the influence of overall facial skin color in determining the health perception of faces via the CIE Lab color space. In spite of some studies a vivid identification of the role of facial colored texture and distribution via color-calibration techniques remains ambiguous [10]. We propose a new technique that detects the facial skin color change through the amount of the oxygen present in the human blood and determines its impact on emotions to expressions. The Pulse Oximeter and 3D skin analyzer are employed to monitor basic facial expressions including anger, happiness, sadness and fear responsible for the natural emotions.

2 Human Skin Coloring

The color of human skin depends solely on the skin chromophores concentration combined by its spatial distribution of melanin and hemoglobin oxygenation [11]. Cotton and Claridge [12] proposed a model for color formation in human skin possessing layered structures comprised of stratum cornea, epidermis, papillary dermis and reticular dermis as shown in Fig. 1. The optical properties of the layers located at the interface reflect the genesis of different skin colors. The study of the skin optics in epidermis and dermis membrane structure has paramount importance because they acquire completely unique absorption, refraction and scattering properties from each other [12, 57].

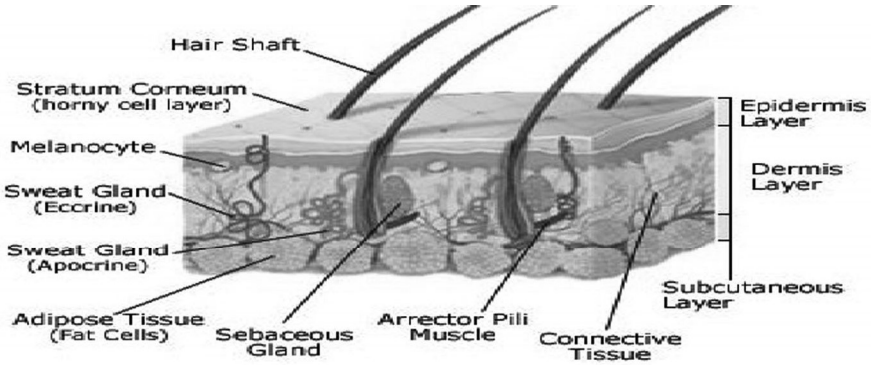

Fig. 1 Different layers and parts of human skin [13]

2.1 Interaction of Light with Epidermis and Dermis Membrane

The epidermis comprised of the epithelial cells which is an outer layer with different melanin volume. The primary chromospheres in the skin layer contain two types of melanin. The first one is brown-black in color and named as eumelanin and the second one is yellowish-red called pheomelanin. Generally, the normal skin possesses some amount of eumelanin often referred as melanin [14]. The biological function of melanin is to protect the skin interior from absorption and scattering of ultraviolet radiation. When skin is exposed to sunlight, the melanocytes produces melanin that make our skin look tanned. The epidermis can further be divided into five sub layers. The bottom and innermost sub-layers are the stratum basale called the basal cell layer. The stratum spinosum termed as the prickle cell layer and the stratum granulosum called the granular cell layer. The stratum lucidum is named the clear layer and the stratum corneum is known as the horny cell layer. In both thick and thin skin types, the variation in stratum corneum of keratinized epithelium cells are responsible for the thickness change of the epidermis [15]. The uneven and rough nature of the stratum corneum surface is due to inadequate diffusion and reflectance in the normal skin. The epidermis layer of the skin reveal many absorption peaks useful for texture patterning and concentration profiling [11]. A part of the spectrum visible to melanin affects the normal transmission in human epidermis responsible for producing a wide range of skin colors from black to white [11]. The epidermis layer being the dermis layer of the skin does not own any blood vessels. Dermis layers in terms of vascular structure is unique from the epidermis layer containing several sensory receptors made of collagen fibers. The main chromophore in the dermis skin layer is hemoglobin which effectively binds the oxygen through vessels and capillaries. Hemoglobin in the absence and presence of oxygen is called deoxy-hemoglobin and oxy-hemoglobin, respectively. Our vein usually contains more than 47 % oxy-hemoglobin [14] which acquires a brighter red-shade than de-oxy-hemoglobin. The uneven relationship between epidermis and dermis is often beneficial and the finger like dermal protrusions called dermal papillae is highly advantageous. The dermis is further categorized into two histologically distinctive layers called papillary dermis and reticular dermis. Difference in their collagen fibers structure makes them distinct [15]. The first layer of the dermis is positioned right below the epidermis where the collagen fibers are tinny [16]. Whereas, the second layer of the dermis called the reticular dermis is located where the collagen fibers are combined into thick bundles. Therefore, the dermis layer being made of thick fibers of collagen the blood vessels set apart the optical properties of the epidermis. The absorption in dermis (bloodless) is weaker compared to the scattering [12] because the main absorbers are the blood borne pigments. In the dermis and epidermis layers, different chromophores are responsible for scattering and absorption processes [11]. In the dermis layer the collagen fibers are in charge of light scattering and blood pigments are accountable for absorption. The contribution from scattering is fixed for the normal skin while the absorption s subjected to the quantity and quality of the blood present.

2.2 Effects of Incident Light on Epidermis and Dermis

The incident light that infiltrates the epidermis layer is diffused by the non-planar surface of the stratum corneum. The strong absorption of short wavelength of visible light by the melanin in the epidermis layer predominates over scattering. On entering the dermis layer the blue component of the incident radiation is lost because of the presence of melanin. Inside the dermis layer, light with shorter wavelength suffer more scattering compared to the longer one. This light penetration gravity and its manifestations in the spectral region is solely determined by the quantity and quality of blood vessels present. The blood pigments absorb blue component of the incident light more strongly than the red one [12] as shown in Fig. 2.

Only a part of the incident light is reflected on the skin surface and the rest penetrates into the skin layers. In the epidermal layer, the light is absorbed by melanin whereas in the dermal layer light suffers multiple scattering by collagen fibers with hemoglobin oxygenation [12]. Light rays upon contacting the dermis layer usually absorbed and reflected. Light with wavelength less than 600 nm produce zero transmission [11]. Light refracted in the epidermis layer containing more melanin gets absorbed before being pass through the stratum corneum. The brown

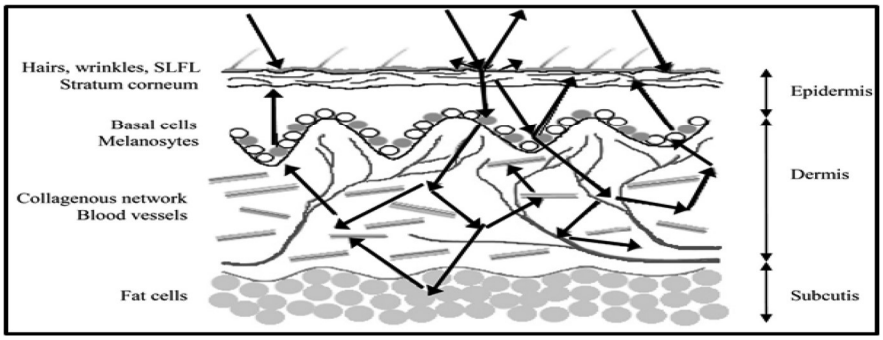

Fig. 2 Schematic diagram of optical pathways in skin [12]

coloration in the normal skin is related to the melanin absorption and red shades originate from the absorption in the vascular dermis layer. Cotton and Claridge [12] considered only the epidermal and dermal layers in their skin model because these two layers being translucent nature are responsible for absorption and scattering of light [12]. Different medium such as melanin, collagen fibers and blood vessels embedded in these layers impart the translucent inhomogeneous material character of the skin.

2.3 Skin Blood Perfusion and Oxygenation

The skin blood perfusion and oxygenation are majorly determined by the cardiovascular, hormonal and circulatory health in humans. The socio-sexual signs of major composition, supremacy and reproductive status in some primates are critically decided by the effect of blood perfusion and oxygenation. In humans, the skin redness is affected by skin vasodilation and vascularization which in turn influence the biological prestige and health. Thus, the blood state of individual affects the skin colour depending on the amount of oxygen present. Interestingly, even at the high levels of sex, women hormone related to the vascularization [17] and vasodilator response [18] arterializes the blood in the skin [19]. The cutaneous vasodilator system response is more towards physical training [20] but is impaired with type 2 diabetes [21] and hypertension [22]. The increase in blood oxygen considerably enhances the aerobic fitness [23] whereas an increase in the de-oxygenation led to the hypoxia and cyanosis (blue tinted skin). These are symptoms of the coronary and respiratory disorder [24]. In human coloration, the skin pigmentation distribution (blood oxygenation and melanin) is a measure of the quality evidence of physiological health related to aging and charm in the face [5, 7]. The brighter the facial skin, higher the charm in femininity or masculinity [9]. The competitors with red faces are found to win or succeed in sports [25, 26]. Consequently, red is interpreted as a clue to supremacy [27] or anger in humans [28]. In addition, women on red attires are seen more beautiful and attractive by men [29]. Stephen et al. [8] established that the skin blood perfusion and oxygenation rigorously affects the healthy appearance of individual faces because attractiveness is a substantial sign of health state [30, 31]. Undoubtedly, the intensely presumed health [30] is the men's choice [32]. It is affirmed that a better health appearance enhances the skin blood oxygen and colour for attraction and mate choice. The change in blood perfusion for dark skinned races are difficult to identify [33]. The skin darkness is known to affect social insights [34] and attraction of faces. Therefore, the people with facial reddening is seen differently from the other ethnic groups having bright and dark skin [8].

3 Quantification of Oxygenation Using Pulse Oximeter

In the red blood cells, oxygen gets bind to the hemoglobin when transported through the lungs from the arterial blood. A pulse oximeter uses two frequencies of light (red and infrared) to determine the percentage of hemoglobin present in the oxygen saturated blood. The percentage is termed as blood oxygen saturation or SpO_2. During measurement, the instrument also displays the pulse rate together with the SpO_2 level. Each lung has approximately

300 million alveoli surrounded by blood capillaries for inhaling oxygen. Since the walls of alveolar and capillary are very thin, the oxygen transient into the alveoli immediately passes into the blood capillaries. Usually in adults, the passage time is about 0.25 s during rest. In this process, a large ratio of the oxygen diffusing into the blood gets bind to the hemoglobin in the red blood cells and a part of it gets dissolve in the blood plasma. The blood enriched with oxygen (arterial blood) flows over the pulmonary veins before entering into the left atrium and ventricle and finally circulates throughout the body organs. The amount of oxygen transported in the body is determined by the oxygen binding capacity of hemoglobin called the lung factor, the hemoglobin concentration so called the anemic factor and the cardiac output termed as cardiac factor. The oxygen carrying capacity is an indicator of its sufficient transport and supply in the body via the lungs. The blood volume pumped by the heart per minute is called the cardiac output and the pumping frequency per minute is termed as the pulse rate. The cardiac function indicators are measured using the pulse oximeter [35–37]. Figure 3 shows the oxygenation mechanism in the human together with the Pulse Oximeter system.

One of the main functions of blood is to capture oxygen from the lungs and then transport it into various tissues in the body. Simultaneously, the blood accepts the carbon dioxide from the tissues and exhale via the lungs. The amount of these gases dissolved in the blood is decided by their partial pressure. In addition, each gas distinct solubility. For instance, only ~ 0.3 ml of oxygen gets dissolve in 100 ml of blood per mmHg which has only ~ 0.05 ml of carbon dioxide solubility. This suggests that human could not get sufficient oxygen if haemoglobin (Hb) was absent in the blood. In fact, Hb being a protein play an important role as oxygen carrier where one molecule of Hb binds 4 molecules of oxygen and per 100 ml of blood about 15 g of Hb is present. To be more precise, 1 g of Hb can bind 1.39 ml of oxygen and 100 ml of blood contains 20.4 ml of oxygen as depicted in Fig. 4.

The Hb bonded to oxygen molecule is termed as oxygenated Hb(HbO_2) and the un-bonded one called deoxygenated Hb. The oxygen saturation signifying the ratio of oxygenated Hb to the total amount of Hb in the blood is given by Eq. (1).

$$\text{Oxygen saturation} = \frac{C(HbO_2)}{C(HbO_2) + C(Hb)} \times 100\,\%$$
$$C(Hb) = \text{Concentration of deoxygenated hemoglobin}$$
$$C(HbO_2) = \text{Concentration of oxygenated hemoglobin} \quad (1)$$

The Hb molecule with binding ratio of 1–4 is stable if and only if all the 4 oxygen molecules are bonded to it otherwise become unstable. It is clear from the figure that Hb exists in the body as a mixture of unstable Hb without oxygen and stable HbO_2 having 4 oxygen molecules. Oxygen saturation is denoted by SaO_2 or SpO_2 called arterial blood oxygen saturation and percutaneous oxygen saturation, respectively. The former one is for the arterial blood while the later one is the detected value by Pulse Oximeter. We employ the Pulse Oximeter for producing the facial skin colour change through the oxygen level in the blood for the four facial expressions and the natural human face.

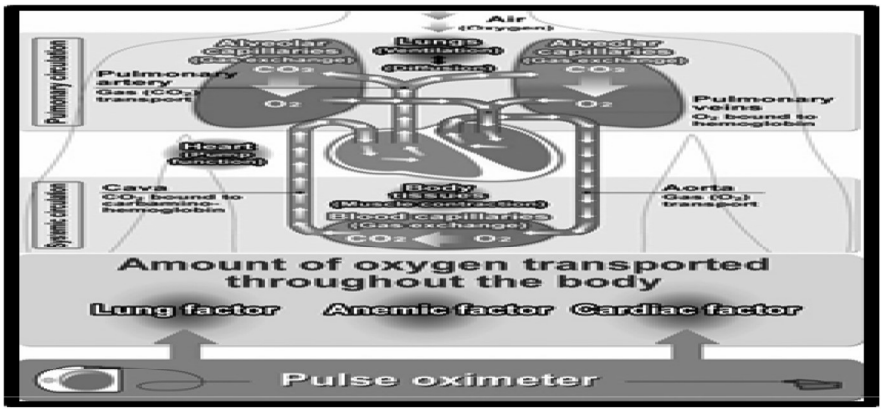

Fig. 3 Human oxygenation process [37]

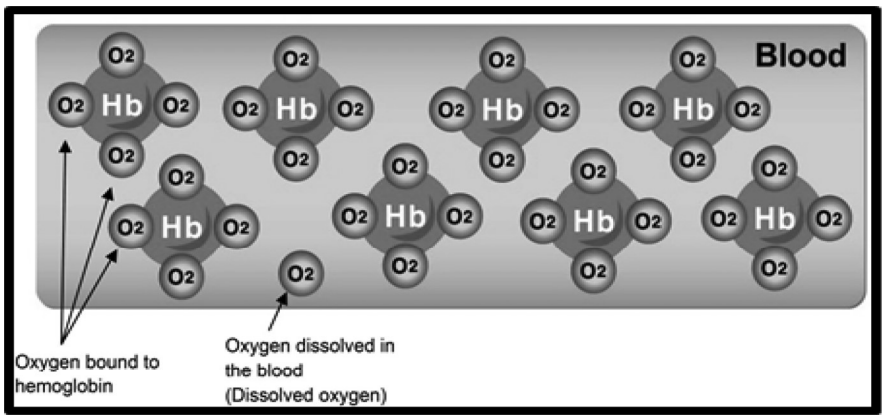

Fig. 4 Attachment of oxygen molecule in blood hemoglobin

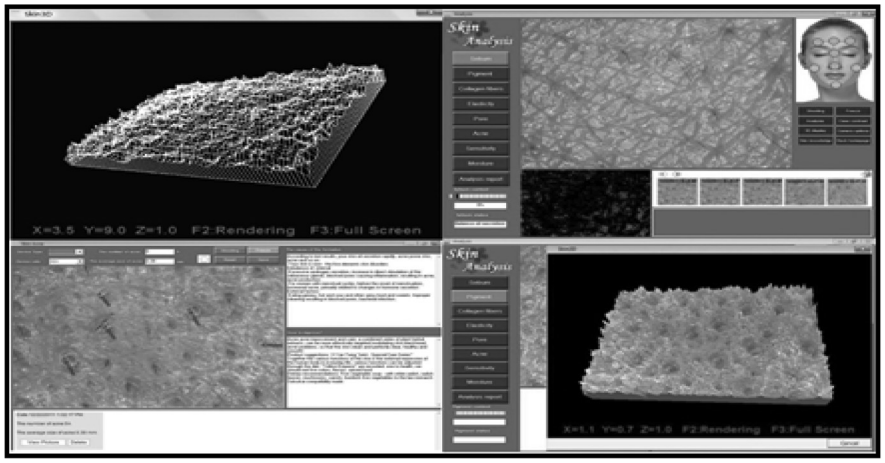

Fig. 5 The 3D skin analyzer

4 Three Dimensional Skin Analyzer

The 3D skin analyzer is a high resolution system used in hospitals for medical surgery which provides a 3D image with various features of collagen fiber including pigment, sebum, acne and moisture. The striking features such as the 3D-Negative capture mode, adjustable focus for a clearer image, compatible iris/hair/skin lens, LED illuminator round the lens, plated layer imported lens, special DSP image processor, optical image stabilizer, auto white balance and contrast adjustment, color temperature filter and dual image for comparison are highly advantageous for precise measurements. A typical 3D skin analysis displaying additional features with 3D negative image, pigment and sebum on the face are shown in Fig. 5.

5 Experiments

Canon Digital Camera, the Pulse Oximeter and the 3D skin analyzer are used for detecting and analyzing facial expressions of genuine human. This camera is a professional one with outstanding image quality and consists of 18MP APS-C CMOS sensor, 14-bit DIGIC 4 image processor, ISO 100–6400, expandable to ISO 12,800, flash-free low-light shooting and shooting range from any angle with a 1040 k-dot variable-angle 7.7 cm (3.0″) screen. The images are captured in real time for four different facial expressions such as anger, happiness, sadness and fear. The Pulse Oximeter that operates with two light frequencies (red and infrared) is used to determine the percentage of oxygen present in the Hb of the blood or SpO_2 [35–37]. For healthy people the oxygen saturation ranges between 90 and

99 % in accord to the emotions but less than 90 % implies hypoxemia state [38–42]. Nevertheless, the oxygen transported in the red blood cells contains oxy-Hb. It is further used to measure and display the pulse rate. This device performs the finger test to measure the blood oxygen level for all four above-mentioned facial expressions. It is well accepted by many medical researchers that oxygen saturation of the blood is a static distribution of the whole body. This distribution has tremendous impact on the skin colour and emotions of the component responsible for the change related to the oxygen intensity in the blood via the lungs [43–45]. Finally, the high resolution 3D skin is used to obtain 3D image of pigment, sebum, acne and moisture.

6 Results and Discussion

The effect of blood oxygenation on facial skin colour is measured and its relation with emotions is understood using different mechanisms. The data are acquired from seven subjects with three female of ages 17, 25 and 35 years and four male of 22, 30, 36, 40 years under different number of partially extreme facial expressions as shown in Fig. 6. Four basic emotions and the natural emotion cover a representative range of these expressions [46]. Each expression is acquired in multiple times by varying with the other expressions. Figures 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 and 22 render clear illustration on how the experiment is conducted. The results show a notable interdependence between the states of emotion and the Hb oxygenation records. Extensive variation in the colours appearance through the expressions is observed. Some of the colours are triggered by deformation assisted blood perfusion while a few are due to capillary stretching. In certainty, extreme emotions like anger or happiness generate a very strong contraction in blood vessels which could cause major reflex blushing making experimental measurement challenging. Here we present the outcome of all seven subjects for four expressions.

Fig. 6 The experimental domain

1. *First subject* the Caucasian male of 36 years old from Middle East in the expression of anger.
2. *Second subject* the Caucasian male of 40 years old from Middle East in the expression of anger.
3. *Third subject* the Caucasian male of 25 years old from Asia in the expression of anger.
4. *Fourth subject* the Caucasian female of 17 years old from Asia in the expression of anger.
5. *Fifth subject* the Caucasian female of 33 years old from Europe in the expression of anger.
6. *Sixth subject* the Caucasian female of 27 years old from Europe in the expression of anger.
7. *Seventh subject* the Caucasian male of 23 years old from Europe in the expression of anger.

All the above measurements displaying our experimental evidences may contribute towards the development of health diagnostics and medical support. Regardless of the variation in ethnic classes the reading on the level oxygenation and de-oxygenation for the emotional expressions follow a correlation as summarized in Table 1.

7 Relationships of Oxygenation and Emotional Expressions

From the table it is evident that the oxygenation level for the emotional expression anger varies between 98 and 99 % while the de-oxygenation level is found to lie within 2–1 % confirming the appearance of facial texture termed as red colour. Conversely, for the emotion happy the oxygenation level decreased to 96–97 % and the de-oxygenation level increased to 4–3 % indicating the facial texture called slight red colour. Furthermore, for the natural emotion the oxygenation level is reduced from 94 to 95 % while the de-oxygenation level lies within 6–5 % supporting the look of facial texture somewhere between red and white. Nonetheless, the emotion sadness produce an