J. Soc. Cosmet. Chem., **32**, 1-14 (January/February 1981)

The variation of skin color in different areas of the human body in a caucasian population in CIE 1976, *L**, *u**, *v** color space

ROBERT P. VAN OORT, D.D.S., *Department of Prosthetic Dentistry, Department of Oral Surgery, University of Groningen, The Netherlands,* JAAP J. TEN BOSCH, PH.D., and PETER C. F. BORSBOOM, *Laboratory for Materia Technica, University of Groningen, The Netherlands.*

Received April 14, 1980.

Synopsis

The prosthetic rehabilitation of patients with a defect in the facial region requires color matching of the prosthesis to the adjacent skin. The investigation of the skin color and the relation between skin colors of different easily accessible skin regions was carried out using a subtractive colorimeter. This method was verified using a spectrophotometer. The objective measurement of the color of the skin is possible if the diameter of the viewing field is taken into account. The data from the spectrophotometer with 5-mm viewing field agreed closely with the results of the subtractive colorimeter. Mean and standard deviations of the color indices in three investigated areas of a population sample are given. The inter-regional correlations of measurements of the color indices for the three measured regions palm, cheek and forearm were weak. The correlations between the color indices measurements were also weak, except for the inner side of the forearm. By means of factor analysis an overall characterisation of the human skin color is presented. To apply the skin color measuring method to a color matching system for facial prothesis, only the measurement in the relevant skin region would be reliable.

INTRODUCTION

One of the objectives of the rehabilitation of patients with facial defects is the inconspicious reconstruction of this defect as soon as possible after operation or trauma. The color match of the prosthesis to the surrounding skin is one of the criteria involved in achieving this objective and, ideally, should be non-metameric. The prosthetic replication of the skin color requires a color system, i.e., a procedure of adjusting colorant mixture until all visually apparent differences in skin color are eliminated. Many color matching procedures for facial prostheses have been developed recently, mainly based on artistic procedures and reproducible color shade guides (1,2). Evaluations of the results of different color matching procedures are not available in the literature. In practice such non-quantitative systems prove to be unsatisfactory in producing an adequate match, especially when taking into consideration length of treatment time and costs. Also evident is the metamerism problem due to the differences in spectra of skin and prosthesis. These differences are present

because the natural skin colorants are instable in vitro and therefore cannot be used as a prosthetic material.

To improve the color matching procedure and to quantify such a system the purpose of the present study involves two objectives: Firstly, the instrumental and quantitative assessment of the variation distribution, difference and correlation of skin color of different parts of the body in a sample population consisting of Caucasian males and females; and secondly, the assessment of the absolute values of skin color from a spectrophotometric measurement of the skin of eleven subjects.

Several methods have been employed to study the color of the skin. Edwards and Duntley (3) performed spectrophotometric measurements of the skin and its pigments in 10 subjects of differing races. This work was concerned with the biophysical and biochemical analytic properties of human skin.

Buckley and Grum (4) did spectrophotometric measurements on the region of the cheek and converted the mean reflectance curve of 10 white subjects into CIE 1931 color specifications. Weiner and Lasker (5,6) introduced two different photovoltmeters in the anthropological field studies, which were directed towards inter- and intrapopulational comparisons of skin color for small wave length regions. Since then Lontz (7) has used the Hunterlab D25 tristimulus colorimetric method for this work. However the latter investigators used too few samples to be of great value in estimating data for a population.

The limited applicability of the tristimulus colorimetric method was discussed by Billmeyer, et al. (8). The main conclusion of this paper was that colorimetric methods in general can only be applied in measurements of color differences. For "absolute" color measurements a spectrophotometric method is required. On the other hand, if one demands easy and fast operation and a reasonable price, colorimeters are to be preferred. For our purpose of comparing the skin colors of various parts of the body and in different individuals in the population we selected a colorimetric method.

For the assessment of the mean and the spread of skin color in a given population we used a spectrophotometer for absolute color measurement. To facilitate relating the physical specifications of color stimuli to the visual perceptions that arise from them, all data were transformed to coordinates L^*, u^*, v^*, of the approximately uniform color space (CIE, 1976).

MATERIALS AND METHODS

For the colorimetric measurements we used a Lovibond MK III (Tintometer Ltd, Salisbury, G.B.) with a movable measuring head connected with fiber optics of 2 m in length. We obtained serial No. AF 751-5271. All observations were done by the first author, his color vision was found to be normal by the Ishihara, the H-R-R test and the 100 Hue Farnsworth-Munsell test. The light source was specified as a CIE Illuminant C (approximately).

The skin is illuminated at an angle of 45° to the surface. The measuring head prevents the leakage of light from the surroundings. The light reflected from an area of 25 mm^2 is received by a fiber optic perpendicular to the surface of observation (Figure 1 and 2). A contact was maintained between the measuring head and the skin. The pressure never exceeded 13 mm Hg, or $1.7 \times 10^3 N/m^2$, i.e., below the subcutaneous capillary

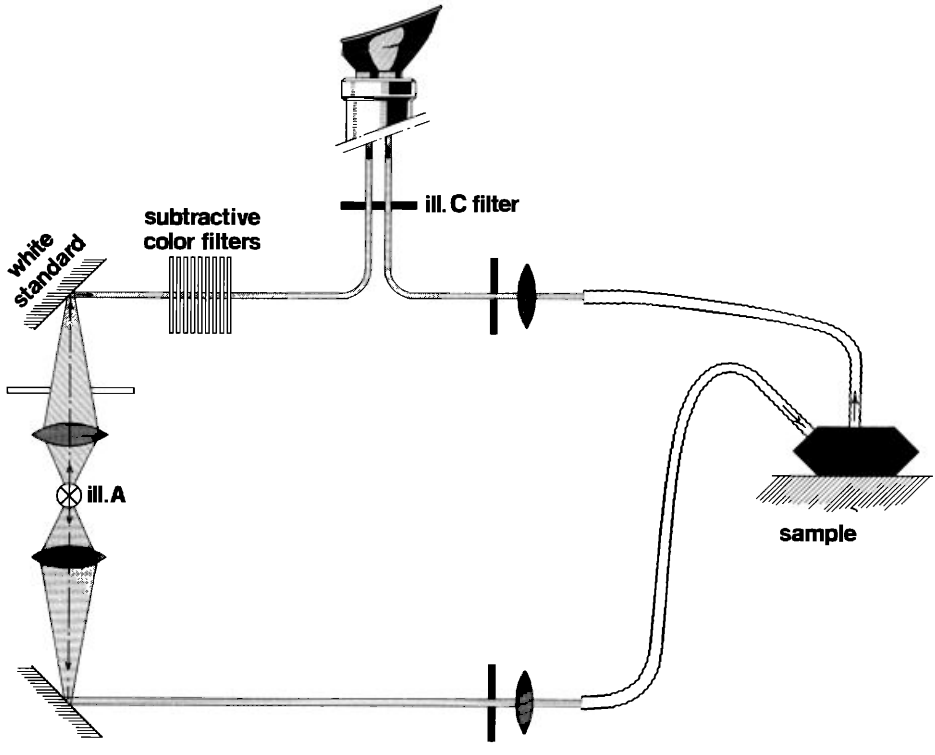

Figure 1. Schematic diagram of the Lovibond MK III substractive colorimeter with fiber optics.

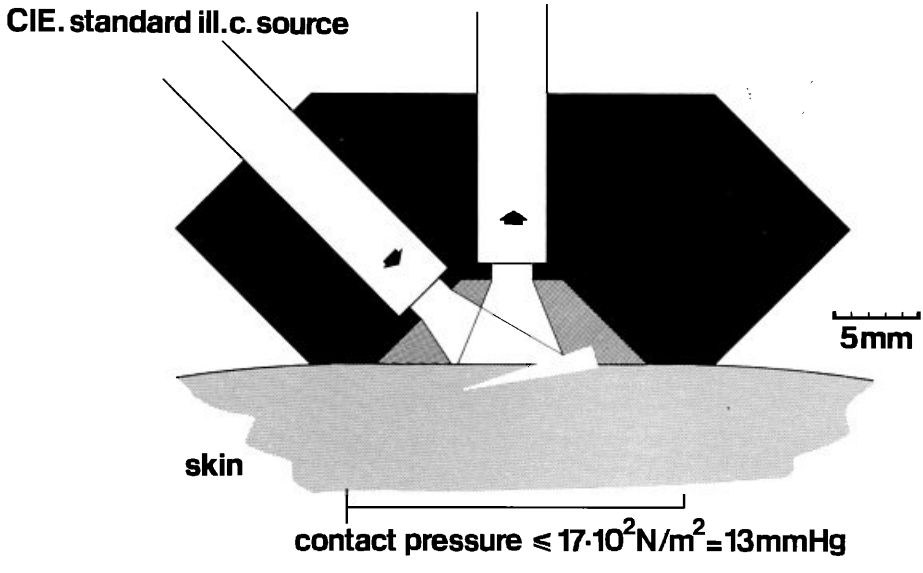

Figure 2. The measuring probe, showing the geometry of the light path. The maximal contact area is at a distance of 4 mm from the measuring area. The pressure is exerted by means of a constant force balance and is below the subcutaneous arterial and venous capillary blood pressure in the supine position of the patient.

bloodpressure level (9). This was obtained by a constant force balance. Thermal effects were avoided because the measuring head was fabricated of thermally isolating plastic. Heating from the light was not commented on by the subjects.

The Lovibond is a subtractive colorimeter which uses the Lovibond-Schofield system, wherein a comparison field is visually matched to light reflected by the sample by means of colored filters. Only two out of three filter colors plus a neutral density filter were used to make a match. A bipartite field of vision of 2° is used. The Lovibond-type color matches are only moderately metameric (10).

A spectrophotometric analysis of the Lovibond system was described by Haupt and Douglas (11) Computations by Haupt, et al. (12) related Lovibond readings to CIE 1931 x, y (chromaticity coordinates) and Y (luminance factor). From these values the L^*, u^*, v^*, coordinates in the CIE (1976) Uniform color space were computed (13). In this color space equal distances between color points represent approximately equal perceptual differences, as long as distances are relatively small. For the present range of colors L^* is related to brightness, the u^* index is related to redness (+) versus greenness (−) and the v^* index is related to yellowness (+) versus blueness (−).

The sample was composed of a hundred dental patients which were referred to the department of oral surgery for treatment with minor oral problems. The patients originated in the northern districts of the Netherlands and contained no people evidently other than the white race. Patients with inflammatory lesions were excluded. They were measured in the 3rd and 4th week of January 1978. The median and mean age of the sample were 26 and 29 respectively. The youngest subject was 8 years, the oldest one was 76 years.

The subject sat upright in a dental chair with the right arm in a horizontal position resting in the elbow support. The observations were respectively taken at the thenar palm of the hand, the inner forearm and the infra-orbital region of the cheek. For each region the measurement took no longer than 1 min. The subject was allowed to acclimatize from the outdoor temperature (8-10°C) to the micro-climate (20 ± 0,5°C) for at least 15 min. There was no direct sunlight in the room. The inner forearm of one male subject was too hairy to measure the skin color. The cheeks of the males and females were all free from cosmetics.

For the spectrophotometric verification measurement we used a Zeiss RFC-3.

VERIFICATION

The brightness reading on the instrument was calibrated by us using MgO surfaces and Munsell chips as described by the manufacturer. A chromaticity calibration was elaborated by the measurement of Munsell individual color standards (matte finish) of 3 × 5 in. in the gamut of the skin. The Lovibond data were compared with the tristimulus data provided by Munsell and obtained from General Electric spectrophotometer curves. Five Lovibond measurements of each standards were averaged. The Munsell standards chosen were: 5 YR 6/4; 5 YR 7/4; 7.5 YR 7/4; 10 YR 6/3; 10 YR 7/4; 10 R 6/4. (Table I).

Later these standards were also measured with a Zeiss RFC-3 spectrophotometer. These data confirmed the G.E. Spectrophotometer data within ± 2% of L^*, u^* and v^*.

Table I
Means and Standard Error of Lovibond MK III and GE Spectrophotometric Measurements of Munsell Color Standards (3 × 5 in.)

10 YR 6/3	L^*	u^*	v^*
Lovibond	60.4 ± 0.3	13.5 ± 0.1	20.7 ± 0.1
G.E. Spectrophotometer	61.44	16.98	25.9
10 YR 7/4			
Lovibond	70.2 ± 0.6	20.2 ± 0.2	31.5 ± 0.5
G.E. Spectrophotometer	71.41	23.78	36.42
10 YR 6/4			
Lovibond	60.9 ± 0.18	27.1 ± 0.1	13.7 ± 0.2
G.E. Spectrophotometer	61.69	30.27	17.50
5 YR 6/4			
Lovibond	59.6 ± 0.6	24.6 ± 0.4	20.0 ± 0.7
G.E. Spectrophotometer	61.65	28.52	25.55
5 YR 7/4			
Lovibond	69.0 ± 2.2	24.3 ± 0.8	21.8 ± 0.8
G.E. Spectrophotometer	71.43	28.82	26.38
7.5 YR 7/4			
Lovibond	70.7 ± 0.7	22.8 ± 1.1	26.0 ± 0.5
G.E. Spectrophotometer	71.65	26.91	30.26

This is good in view of the different geometry of measurement of these two spectrophotometers.

As Table I indicates, our Lovibond flexible optic Tintometer produced a desaturated color reading compared to the Munsell G.E. and Zeiss spectrophotometers. It appeared that the deviation was roughly in the same direction of the L^*, u^*, v^* color space for all standard colors. Therefore all Lovibond measurements, except those in Table I, were corrected with + 1.5; + 3.6; + 4.6; for L^*, u^*, and v^* respectively, being the mean color differences of the two instrumental readings.

For the spectrophotometric measurements of skin color a Zeiss RFC-3 with Serial Number 96870 was used. The skin of the forearm and palm was illuminated spherically, the measuring beam was at 8° with the normal. The field diameter was variable over 5 mm, 15 mm and 30 mm. The skin of the cheek could not be measured with this instrument.

The second sample was composed of eleven white subjects, 6 female and 5 male, and visually selected to rather extreme variance in skin color. The measurements took place in the third week of November 1979. The median and mean age of the sample were 28 and 29 respectively. The range was from 24 to 45 years old. The results are shown in Table II. A representative diagram of the differences of measurement in the L^*, u^*, v^* color space between the Lovibond MK III and the Zeiss RFC with 30-mm field can be read from Figure 3a and b for each subject separately. We presented only the data for outer forearm because this area has approximately similar pigmentation as the facial skin.

Table II

Means and Standard Deviations of Corrected Lovibond MK III Measurement (Values Corrected to Munsell Standards) and Zeiss RFC-3 Spectrophotometric Differences of Palm, Inner Forearm, and Outer Forearm for 11 Subjects with Increasing Field Diameter

	Lovibond values		
	L^*	u^*	v^*
Palm	56.49 ± 1.9	11.3 ± 1.4	11.78 ± 0.9
Inner forearm	62.88 ± 1.9	9.72 ± 1.6	16.81 ± 2.4
Outer forearm	55.55 ± 1.4	15.79 ± 2.2	21.28 ± 1.9
	Zeiss-Lovibond differences—Zeiss at 5-mm field diameter		
	ΔL^*	Δu^*	Δv^*
Palm	1.79 ± 1.6	3.5 ± 1.8	1.6 ± 1.3
Inner forearm	1.07 ± 0.8	2.8 ± 1.9	1.65 ± 1.7
Outer forearm	2.1 ± 1.8	2.92 ± 1.8	1.66 ± 1.4
	Zeiss-Lovibond differences—Zeiss at 15-mm field diameter		
	ΔL^*	Δu^*	Δv^*
Palm	3.97 ± 2.2	10.24 ± 2.5	3.62 ± 1.8
Inner forearm	3.7 ± 1.4	8.7 ± 1.9	4.7 ± 1.7
Outer forearm	4.15 ± 2.9	9.69 ± 2.5	4.17 ± 1.5
	Zeiss-Lovibond differences—Zeiss at 30-mm field diameter		
	ΔL^*	Δu^*	Δv^*
Palm	6.62 ± 2.0	12.1 ± 2.0	6.44 ± 1.5
Inner forearm	4.60 ± 1.5	11.55 ± 2.4	5.18 ± 1.6
Outer forearm	6.07 ± 3.0	10.86 ± 2.3	5.62 ± 1.8

The differences in the measurement results between the Lovibond MK III and the Zeiss RFC-3 with 5-mm field diameter are small. The conclusion is justified that the different beam directions of the two instruments only affect the measurement results to a relatively small degree.

The difference between Lovibond and Zeiss with the field diameter of 15 and 30 mm is probably due to volume reflection of light as it penetrates a turbid medium like the skin. Besides penetration, the scattering process also causes light travel parallel to the surface. This results in relative loss of light and hence a lower L^*, when a small area is used. This phenomenon together with the different volume reflection coefficients of the shorter and longer wavelengths also explains the relatively larger redness-value(u^*) of the spectrophotometric measurement with the largest viewing opening compared to the smallest opening. Also, absorption differences due to these pathlength differences may play a role. These effects will be further investigated.

The problem of the measurement of the translucent medium was discussed by Hunter (17). He advises using an instrument with an illuminating beam of smaller diameter than the diameter of the viewing window itself. The difference between the diameters of the window and the beam should increase with depth of light penetration of the specimen. However, because of the curvature and pliability of the skin we do not recommend the use of such a large field diameter, because the skin of the palm and the

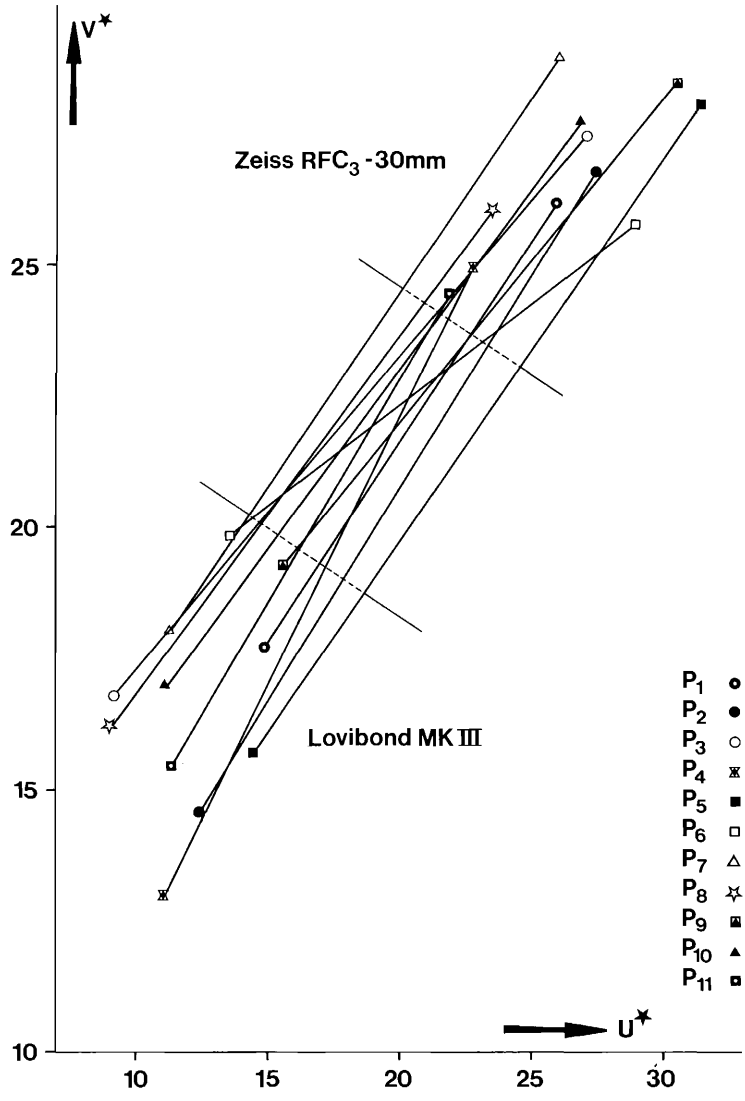

Figure 3a. u^*-v^* color differences of the outer forearm of 11 persons measured using Lovibond MK III versus Zeiss RFC-3 with 30-mm viewing field diameter. The dotted lines represent the boundaries of the measurements of the two instruments.

arm has a tendency to bulge into the measuring sphere. For the cheek this penetration is stronger.

RESULTS

The precision of measurement at the same occasion was determined by ten repeated measurements after repositioning of the measuring head in one subject by one observer. For the skin in the zygoma area the standard deviations were found to be 1.1; 0.5; 0.9; for L^*, u^*, v^* respectively. However in more color-saturated skin areas these

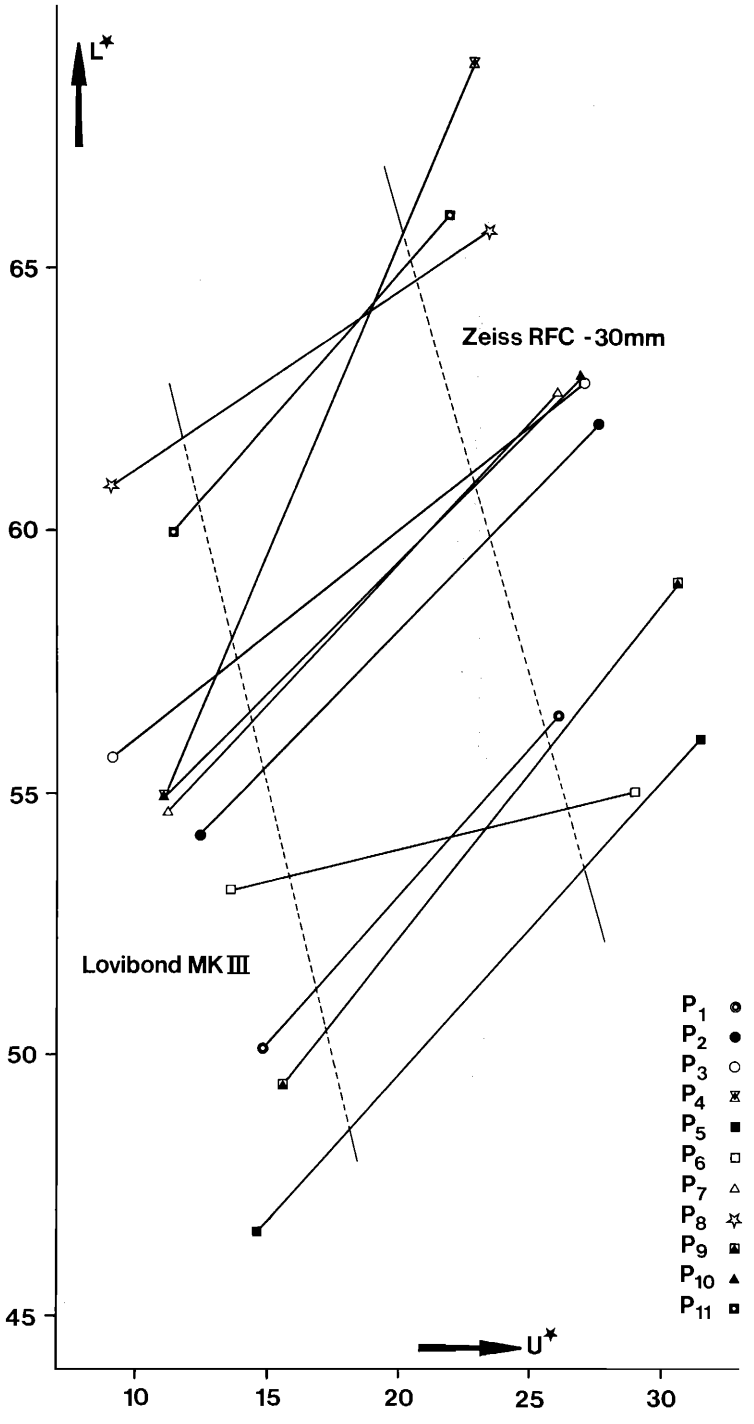

Figure 3b. L^*-u^* color differences of the outer forearm of 11 persons measured using Lovibond MK III versus Zeiss RFC-3 with 30-mm viewing field diameter.

values were 1.8; 0.9; 0.7 for L^*, u^*, v^* respectively. This increase in standard deviations was confirmed by measurement of the Munsell standards with increasing color saturation.

The magnitude of normal variation caused by time and precision of measurements, was registered in one subject by means of 9 measurements, in the zygoma area, three every hour during morningtime. The standard deviations were 1.9; 0.6; 0.8 for L^*, u^*, v^* respectively.

The skin color measurements of 100 subjects demonstrate an approximately normal distribution of the color indices of the forearm, the palm and the cheek. In Figure 4 these distributions are shown for u^*.

The means and standard deviations of u^*, v^*, L^* indices for the three measured skin areas are shown in Table III.

Only for the palm and the cheek is the difference for the mean u^* between females and

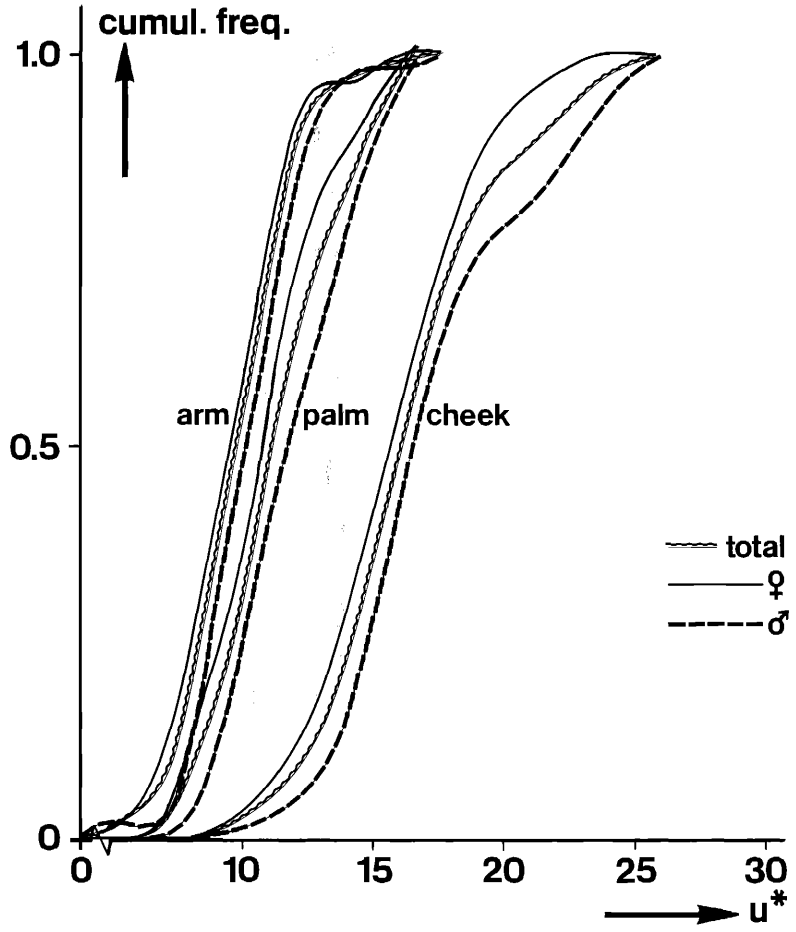

Figure 4. The relative u^* color coordinates for the inner side of the forearm, the thenar palm of the hand and infra-orbital area of the cheek are approximately normally distributed over the populations.

Table III
Means and Standard Deviations (Denoted with S.D.) of the Sample (Values Corrected to Munsell Standards)

		N	L^*	S.D.$_{L^*}$	u^*	S.D.$_{u^*}$	v^*	S.D.$_{v^*}$
Inner Forearm:	Male	48	57.0	5.9	10.2	2.1	13.0	2.4
	Female	51	56.1	5.3	9.5	2.1	12.2	2.3
	Total	99	56.5	5.6	9.8	2.1	12.6	2.3
Palm:	Male	49	51.4	5.0	11.9	2.4	9.6	2.1
	Female	51	52.7	5.2	10.8	2.3	9.9	2.2
	Total	100	51.8	5.2	11.4	2.4	9.7	2.1
Cheek:	Male	49	45.8	7.3	17.4	3.6	10.5	2.3
	Female	51	47.2	7.5	15.8	3.0	10.8	4.2
	Total	100	46.5	7.4	16.6	3.4	10.7	3.4

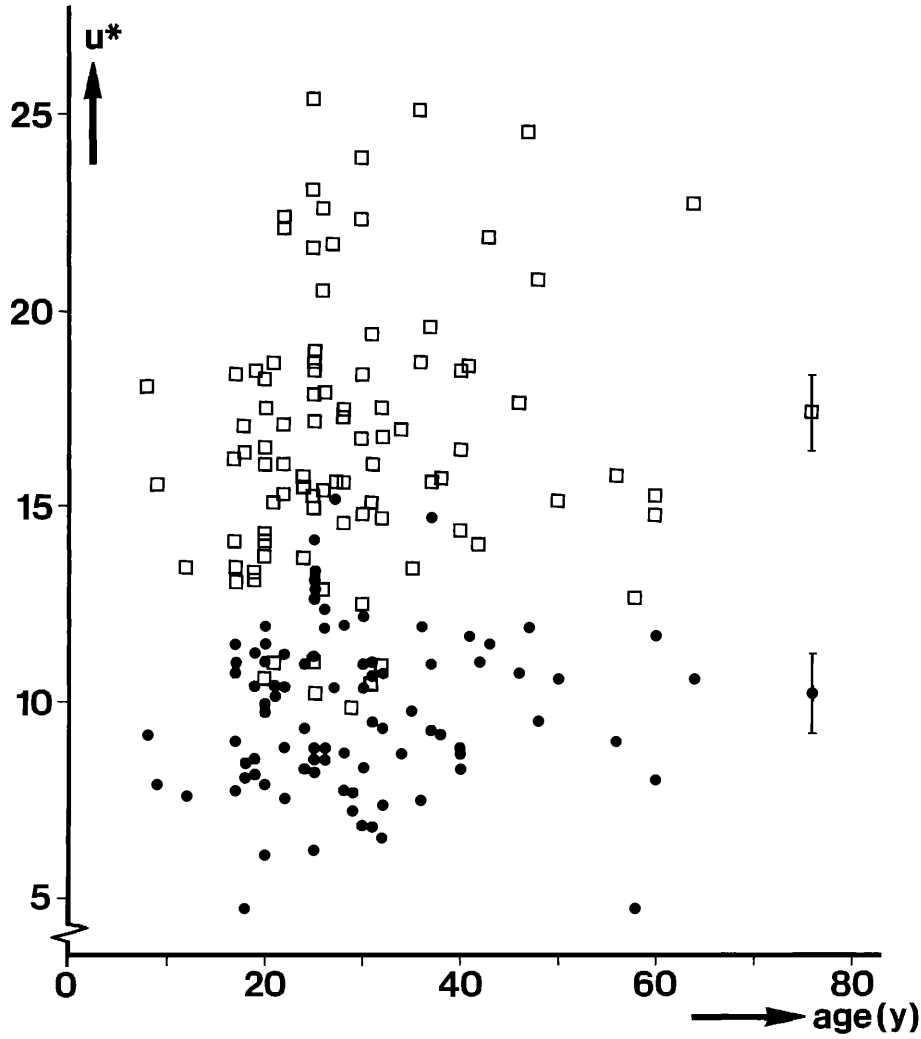

Figure 5. Scatter diagram of u^* versus age of the inner forearm ● and the cheek □. A weak correlation is present.

Table IV
Summary of Correlation Analysis of u^* Versus v^* and u^* Versus L^* and v^* Versus L^*. r is the Correlation Coefficient, P is the Level of Significance. N.S. Indicates $P > 0.05$

	N	$r_{u^*v^*}$	P	$r_{u^*L^*}$	P	$r_{v^*L^*}$	P
Palm:	100	0.28	<0.01	−0.25	<0.05	0.17	N.S.
Cheek:	100	0.06	N.S.	−0.41	<0.001	0.21	<0.05
Arm:	99	0.61	<0.001	−0.03	N.S.	0.16	N.S.

males significant ($P < 0.05$). L^* and v^* do not differ significantly between male and female.

The u^* colorindex (redness), the v^* colorindex (yellowness) and the L^* index of the three skin areas of the subjects are not related to the ages of the persons. For the index u^* this is illustrated in Figure 5. The results for v^* and L^* are similar.

The correlation of the chromaticity indices u^* versus v^* and for u^* versus L^* for every measured area separately is given in Table IV.

The statistically significant correlation ($P < 0.01$) u^* versus v^* for the arm and the absence of u^* versus v^* correlation for the cheek can be read from the scatter diagram in Figure 6.

The color index relations between the three areas are quantitatively represented in Table V.

To discover an overall relationship in the three color indices, measured in the three areas for the sample of 99 subjects a factor analysis was carried out. Every subject of the sample is characterized by nine variables, i.e., 3 (L^*, u^*, v^*) times 3 (palm, cheek, arm). Three factors are orthogonally rotated according to the varimax criterion (14, 15). The loading is a measure of the correlation between the factor and the variable. The results are presented in Table VI.

The first factor has positive loadings. Its high loadings are for V1, V2, V5, V7 and V8, or redness index and yellowness index for the palm and the innerforearm and the yellowness index of the cheek. This is a factor of chromaticity.

The second factor has positive factors except for redness index of the palm. Its high loadings are for V3 and V9, luminous reflectivity of the palm and the inner forearm. This is a luminous reflectivity factor, excluding the cheek.

The third factor is certainly puzzling with only negative and positive loadings. Its high loadings are for V4 and V6. The main emphasis of this factor seems to be on the pigmentation of the facial skin.

DISCUSSION

The precision of measurement on a particular skin sample tends to be inversely related to its saturation. Psychophysical color difference measurements converted in the L^*, u^* and v^* color space seem to confirm this (16).

The color of the skin is determined by the different translucent layers, the particular pigments in each of these layers and the degree of the light scattering due to difference

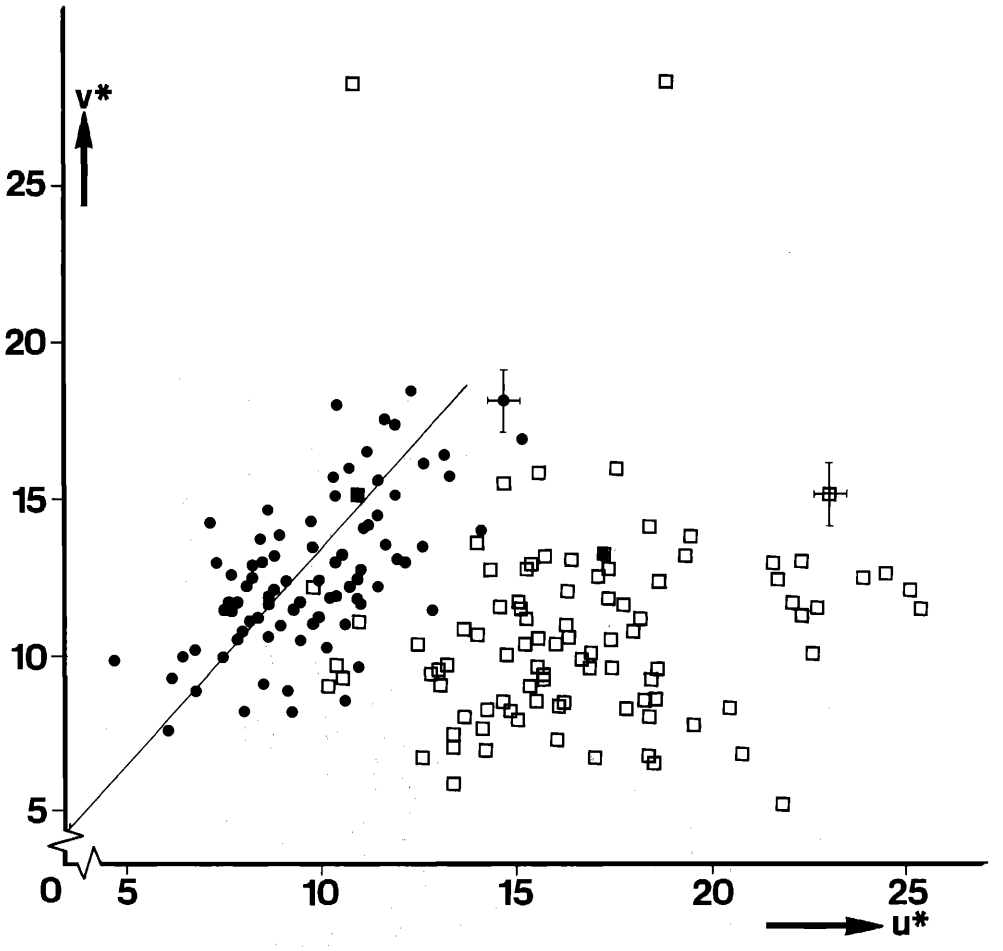

Figure 6. Scatter diagram of u^* versus v^* for the inner forearm ● and the cheek □. Only the correlation $r_{u^*v^*}$ of the inner forearm is significant $P < 0.001$. The regression equation for the forearm is $v^* = (2.6 \pm 0.7) + 0.56\,u^*$.

in turbidity (3). This translucency of the living human skin and its effects is difficult to investigate at the moment.

In maxillofacial prosthetics the main interest is directed towards the facial area. The results in color differences obtained by the colorimetric method between the three investigated areas show a significantly higher $S.D._{u^*}$ and $S.D._{L^*}$ ($P < 0.01$) (Viz. Table III) of the melanin pigmented skin of the cheek than of the relatively unpigmented inner forearm. This relates to the "normal" population variation of pigmented areas. Furthermore, the significantly higher redness u^* value ($P < 0.01$) of the cheek and the palm in comparison to the forearm can be explained by the bodily distribution of arterial bloodsupply, sizes of blood vessels and melanine content of the stratum mucosum and the epidermis (3). A similar explanation may hold for the higher v^* value of the inner forearm, which may correlate with a higher carotene content. The significantly lower L^* of the cheek ($P < 0.01$) and the palm ($P < 0.01$) compared with the inner forearm is probably caused by the degree of scattering due to a thicker stratum mucosum. The same explanation might hold for the negative relationship

Table V

Summary of Correlation Coefficients r Between the Three Areas. P is the Level of Significance. N.S. Indicates $P > 0.05$

	N	u^*	P	v^*	P	L^*	P
r Palm/Cheek:	99	0.14	N.S.	0.17	N.S.	0.28	<0.01
r Palm/Forearm:	99	0.32	<0.01	0.25	<0.02	0.31	<0.01
r Cheek/Forearm:	99	0.27	<0.01	0.33	<0.01	0.31	<0.01

Table VI

Variables	Orthogonal Rotation of Factors		
	1	2	3
$V1$ u^* palm	.647	−.484	−.034
$V2$ v^* palm	.518	.065	−.033
$V3$ L^* palm	.071	.825	−.041
$V4$ u^* cheek	.254	.175	.854
$V5$ v^* cheek	.531	.303	−.137
$V6$ L^* cheek	.216	.352	−.797
$V7$ u^* inner forearm	.774	.058	.170
$V8$ v^* inner forearm	.704	.301	.104
$V9$ L^* inner forearm	.197	.619	−.024
Explained Variance (%)	27.31	18.04	13.43

(Table IV) between u^* and L^* of the palm and u^* and L^* of the cheek which indicates the relatively large degree of light scattering in these skin areas.

The weak correlations of either u^* (redness) or v^* (yellowness) index between the three investigated skin areas (Table V and VI) indicates that it is useless to measure the color of the inner forearm or palm as a basecolor for the facial prosthesis. The instrumental determination of skin color and conversion and preparation of a color recipe should be exerted directly on the facial skin. The development of a preferably spectrophotometric instrument suitable for such an intricate situation is desirable for the near future.

The distribution of skin colors in our population in relative units can be determined from our colorimetric data. 95% of the population is within a width of four standard deviations. For the cheek the width of this range amounts to $\Delta L^* = 29.6$; $\Delta u^* = 13.6$; $\Delta v^* = 13.6$ (Viz. table III).

Absolute data can only be roughly derived assuming that the spectrophotometric values at 30-mm diameter correspond to visual perception of the skin. Then the mean and standard errors of the distribution of a skin pigmented similarly to the face amounts to $L^* = 61.63 \pm 1.4$; $u^* = 26.73 \pm 0.9$; $v^* = 26.9 \pm 0.4$.

Climatic, physiological and ethnical factors will probably make it necessary to modify these color data, before it will be applicable in the artificial cosmetic replication of facial skin. Such work is in progress.

ACKNOWLEDGEMENTS

Thanks are due to P. Padmos, Ph.D. and F. W. Billmeyer, Jr., Ph.D., for their suggestions and discussions concerning to the measuring method, to Mr. R. Kroeze

s.c.d. from Borg-Warner Chemicals, for his valuable cooperation during the spectrophotometric measurement, to Miss A. van Hoogen for typing the manuscript, to Mr. H. Leydsman for the construction of the constant force balance and to Mr. Chr. Lingeman for preparing the illustrations.

REFERENCE

(1) T. O. Aina, S. M. Wright, and E. Pullen-Warner, The reproduction of skin color and texture in facial prostheses for negro patients, *J. Prosthet. Dent.*, **39**, 74-79 (1978).
(2) L. Fine, J. E. Robinson, G. W. Barnhart, and L. Karl, New method for coloring facial prostheses, *J. Prosthet. Dent.*, **39**, 643-649 (1978).
(3) E. A. Edwards and S. Q. Duntley, The pigments and color of living human skin, *Am. J. Anat.*, **65**, 1-32 (1939).
(4) W. R. Buckley and F. Grum, The measurement of skin color, Spectrophotometric technique, *J. Soc. Cos. Chem.*, **15**, 79-85 (1964).
(5) J. S. Weiner, A Spectrophotometer for measurement of skin colour, *Man*, **253**, 152-153 (November 1951).
(6) G. W. Lasker, Photoelectric measurement of skin color in a Mexican Mestizo population, *J. Phys. Anthropol.*, **12**, 115-122 (1954).
(7) J. F. Lontz, J. W. Schweiger, and A. W. Burger, *Standards of colormatching, general concepts for pigment selection*. Presented at the first international symposium on facial prosthetics, Arnhem (1976).
(8) F. W. Billmeyer, Cautions required in absolute color measurement with colorimeters, *Official Digest*, **34**, 1333-1342 (1962).
(9) A. Jarrett, ed., *The Physiology and Pathophysiology of the Skin* (Academic Press, London, 1973), pp. 683-686.
(10) D. B. Judd and G. Wyszecki, *Color in Business, Science and Industry* (John Wiley and Sons, New York, 1975) pp. 201-202.
(11) G. W. Haupt and F. L. Douglas, *Chromaticities of Lovibond glasses, J. Opt. Soc. Am.*, **37**, 172 (1974).
(12) G. W. Haupt, J. C. Schleter and K. L. Eckerle, *The ideal Lovibond color system for CIE standard illuminants A en C shown in three colorimetric systems* (U.S. Natl. Bur. Std., TN-716, 1972).
(13) R. S. Hunter, *The Measurement of Appearance* (John Wiley and Sons, New York, 1975), pp. 300-305.
(14) M. J. M. Brand-Koolen, *Factoranalyse in het sociologisch onderzoek*. Explicatie en evaluatie van enige modellen, Diss. Leiden (1972).
(15) Wesp, *Waarlijk eenvoudig statistisch Pakket*. Door L.Th. van der Welle, et al. Rekencentrum-publicatie 8, Groningen (1977).
(16) A. R. Robertson, The CIE 1976 Color-Difference Formula, *Color Research and Application*, 2, 7-11 (1977).
(17) R. S. Hunter, *The Measurement of Appearance* (John Wiley and Sons, New York, 1975), p. 203.