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QUANTITATIVE STUDIES ON THE EFFECTS OF NON-IONIZING RADIATION ON THE SKIN*

I. Spectral Reflectance of the White and Negro Skin Between 440 and 1000 mμ

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QUANTITATIVE STUDIES ON THE EFFECTS OF NON-IONIZING RADIATION ON THE SKIN*

I. SPECTRAL REFLECTANCE OF THE WHITE AND NEGRO SKIN BETWEEN 440 AND 1000 mμ

by

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1 May 1951

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ABSTRACT

QUANTITATIVE STUDIES ON THE EFFECTS OF
NON-IONIZING RADIATION ON THE SKIN

I. SPECTRAL REFLECTANCE OF THE WHITE AND
NEGRO SKIN BETWEEN 440 AND 1000 mμ

The OBJECT of the study was

To investigate the spectral reflectance of the white and negro skin under varied tan conditions over an extended range to 1000 mμ.

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RESULTS AND CONCLUSIONS

The maximum reflectance of the white skin was found between 720 and 820 mμ; it is shifted to about 840 mμ with increasing tan. On the negro skin it is found at about 900 mμ. Two reflectance minima, probably caused by water absorption bands, were found; a flat one near 760 mμ becomes less pronounced with increased tan, and is completely masked on the heavily tanned negro skin; the other minimum at 980 mμ is strongly pronounced, and only slightly influenced by the degree of tan. The reflection difference of untanned and tanned, as well as of white and negro skin, tends to disappear with increasing wavelength.

RECOMMENDATIONS

Reflectance measurements and their evaluation should be extended beyond 431 mμ into the ultraviolet range on one hand, and beyond 1000 mμ into the infrared on the other hand.

The meaning of the present data with regard to the absorption of black-body radiation should be examined.

Other parts of the surface of the human body should be studied.

The effects of known amounts of radiant energy under variation of the time-intensity relation should be investigated.

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QUANTITATIVE STUDIES ON THE EFFECTS OF
NON-IONIZING RADIATION ON THE SKIN

I. SPECTRAL REFLECTANCE OF THE WHITE AND NEGRO SKIN BETWEEN 440 AND 1000 mμ

I. INTRODUCTION

Spectrophotometric reflectance measurements of the human skin in the visible range of the spectrum (440 to 700 mμ) have been made by several investigators, including Edwards et al. (1). Their principal objective was the study of the components which determine the skin's color topography and of the variation of these components with respect to race, sex, age, etc. On a single case, the method was used to analyze the pigment changes after exposure to sunlight (2). Similar studies of the complexions of a greater number of subjects were made from the viewpoint of lighting design (3).

In the present investigation the spectrophotometric method, when necessary in combination with other methods, was used to find quantitative relations between non-ionizing radiant energy and its effects on the skin, mainly erythema and/or tan.

Since these effects manifest themselves outwardly as changes of the skin color, the spectrophotometric analysis of the skin color and of its time course, appeared to be an appropriate method not only to describe the radiation effect quantitatively but also to bring it into a quantitative relation to the cause, that is, to the amount of radiant energy and its time-intensity components. An essential advantage of the method is that it can be applied to the living skin without interfering with the biological processes.

A knowledge of the spectrophotometrically measured skin reflectance can be expected to yield useful quantitative information on what might be called the spectral protective coefficient of the skin, that is to what degree, under different skin conditions, the incident radiant energy may be able to penetrate and to become biologically effective.

Since most of the existing colorimetric knowledge of the skin is based upon individual spectrophotometric reflectance measurements (1) (2), it appeared desirable not only to establish a broader basis by measuring the skin reflectance of a large group of individual whites as well as negros, but also to extend the range beyond the 700 mμ limit to 1000 mμ, which is the limit determined by the present instrumentation. The reason for this extension is based upon the desire to know more about the behavior of the skin toward thermal (burn producing) radiation which may originate, for example, from the aerial burst of nuclear weapons.

II. EXPERIMENTAL

The reflectance curves were taken with a General Electric recording spectrophotometer of the design of Arthur C. Hardy. The measuring range, 431 to 1000 mμ, was determined by the instrument. The instrument was cali-

brated daily, and the white MgO reflection standards were prepared fresh each day and checked against a Vitrolite working standard calibrated by the National Bureau of Standards. The MgO standards were prepared by an improved process developed in this laboratory. The process will be described separately.

The selection of the skin areas to be measured was made as follows: One area as untanned as possible, a second area as excessively naturally tanned as possible, and a third, normally tanned area were chosen. A part of body skin with low melanin content which is practically never exposed to sunlight would have been the most desirable least tanned area. Because of the present design of the spectrophotometer the proper and safe positioning of such a body part was impractical, for it is essential to bring the area to be measured (a circular spot of 1" diameter) in good and easily maintainable contact with the opening of the integrating sphere. The area selected as a good approximation to the untanned, or rather least tanned part of the body, was the inside of the right forearm, midway between the wrist and elbow. For the most tanned area the outside of the left arm midway between the wrist and elbow was chosen. This area becomes heavily, naturally tanned during the summer with what may be called "driver's tan." Since the measurements were made at the end of summer, it can be assumed that this "driver's tan" had reached its maximum. For the normally tanned area the forehead over the left eye was chosen.

The recordings were taken at low speed in order to minimize any inertia of the stylus. It took four and one half minutes for a single recording. The variation of pressure on the skin area being measured caused by unwanted movement of the subject could change the blood circulation and thus distort the reflectance. Therefore, it was of considerable importance that the subject remain as still as possible and not vary the pressure against the integrating sphere during the recording. It was found that under the present experimental conditions this could be accomplished satisfactorily.

Reflectance measurements were made on 113 subjects, namely, 50 white males, 21 negro males, 21 white females, and 21 negro females. Two original reflectance diagrams are shown in Figure 1 and Figure 2; due to the design of the recording spectrophotometer used, the abscissa is non-linear. In this report no differentiation was made as to complexion, age, or sex. The total number of subjects used was not large enough to be analyzed according to these factors and still yield statistically acceptable results. The reflectance values were read from the curves at 20 mμ intervals. The arithmetic mean values were obtained by the class interval method, as were the standard deviations which were calculated according to the statistical definition of this term.

III. RESULTS AND DISCUSSION

The results of the statistical computation are compiled in Table 1 and shown in the figures 3, 4 and 5. The non-linear abscissa of Figures 1 and 2 was used in these graphs to facilitate the comparison. The distribution of the data was found to be rectangular rather than normal. In 84% of the determinations at least 68% of the cases lie within $+\sigma$ and $-\sigma$.

A. General Discussion of the Reflectance Graphs

In the spectral region below 700 mμ the reflection minima at 542 mμ and 576 mμ (due to the absorption by oxyhemoglobin) and at 556 mμ (due to the absorption by reduced hemoglobin) become less pronounced (blunted) as the pigmentation increases. This effect can be seen on Figure 1, and even more strikingly on Figure 2. Earlier observations (1) are thus confirmed.

In the spectral region above 700 mμ two hitherto unpublished reflection minima can be seen on the white and on the not too heavily tanned negro skin. The more pronounced minimum is found at 980 mμ. It is probably due to a water absorption band, and it seems to be influenced only slightly by the degree of tan. It was never found as strongly blunted as the oxyhemoglobin and hemoglobin minima even on the additionally tanned negro skin (curve 2 in Figure 1, and curve 2 in Figure 2). The second minimum is seen near 760 mμ. It appears as a flat dip on the least tanned white skin (curve 1 in Figure 1) and becomes less pronounced with increased tan. On the least tanned negro skin it can hardly be seen, and on the heavily tanned negro skin it is completely masked by the melanin, which, in general, dominates the reflection of the negro skin as can be seen from the slope of the curve in comparison to the white skin (see Reference (1), Figure 4). This second minimum probably also can be ascribed to a water absorption band. Transmittance measurements of distilled water, tap water, and isotonic saline solution in a 50 mm layer showed not only a sharp dip (near 970 mμ) to about 10% transmittance, but also a flat and broad dip, beginning at about 710 mμ and extending from 730 to 780 mμ at about 93% transmittance (for distilled water and saline solution) and 84% transmittance (for tap water). As can be seen from the reflectance curves (Figure 1 and Figure 2), the maximum of reflection in the spectral region under investigation occurs between 720 and 820 mμ for the white untanned skin, and is shifted towards greater wavelengths with increasing pigmentation to about 840 mμ for the tanned white skin, and to about 900 mμ for the negro skin. A third reflection minimum was found at 845 mμ on the least tanned area of some white subjects with high reflectance in that wavelength region. It is far less pronounced than the minimum at 720 mμ; and a very light degree of pigmentation already causes a complete masking. This minimum too probably can be ascribed to a weak water absorption band at 845 mμ.

At this stage of the investigation concern was not given to the absolute values of the reflectance maxima. It is known that different parts of the body surface show different reflectance values, and that some parts of the body surface show considerable seasonal fluctuations in their reflectance. An attempt was not made to establish statistically a general, that is a year-round, reflectance curve for the different skin areas and different races respectively.

Thus it has to be kept in mind that the results are to be applied only for the three measured areas and for the time of the year, namely, the end of summer, when the reflectance measurements were performed. Although the results confirm earlier investigations (3) of the seasonal factor, a numerical comparison cannot be made due to the difference in the experimental conditions. For a detailed study of the seasonal factor, its geographical and occupational components should be taken into consideration.

However, the results could be compared with an unpublished reflectance curve taken in January at the National Bureau of Standards over the same wavelength range and from the same skin area (forehead above the left eye). The expected higher reflectivity for the January measurement was found. Because of the seasonal factor in this investigation, a numerical comparison with the results of the spectrophotometric complexion studies (3) cannot be made.

No particular attention was paid in the present study to the blood component of the skin color and its variation nor to the individual pigments (melanine, melanoid, carotene) which play a role in determining the skin color. This will be done in a later stage when the relation between applied radiant energy and biological effect, mainly erythema and tan, is studied quantitatively. Furthermore, the colorimetric aspect of the problem (evaluating the reflectance measurements for dominant wavelength, relative brightness, and purity) was not regarded as part of this investigation. It also was not considered part of the present investigation to study in detail the influence of age, sex and complexion.

B. Special Discussion of the White and Negro Skin and of the Additional Pigmentation

The relation between reflectance and concentration or thickness of the reflecting substance cannot be expressed in a physical law similar to Beer's and Bouguer's laws for transmittance. Therefore, the measured reflectance values do not allow, at this time, a quantitative conclusion for the total and relative amount of added pigment. However, the following conclusions can be made from the present measurements.

A comparison of the untanned areas (inside right forearm) of white and negro skin is made in Table 2, Column 2, and is shown in curve 1 of Figure 6. The spectral reflectance of the white skin area is made to equal 100; thus, the curve shows the variation of the relative spectral reflectance of the negro skin through the spectral range under study. A similar comparison for the most tanned areas (outside left forearm) for both skins is made in Column 3 of Table 2 and is shown in Curve 2 of Figure 6.

As can be seen from the tables and curves, the relative spectral reflectance values above 600 mμ increase steadily and, at the same time, converge mutually as well as towards the reflectance values of the untanned and tanned white skin respectively. In other words, the reflectance differences of the negro skin tend to disappear with increasing wavelength.

The same conclusion can be made from a similar comparison of the least tanned and the most tanned areas for the white and the negro skin. The spectral reflectance of the least tanned areas was made to equal 100, and the relative spectral reflectance values are shown in Table 2, Columns 4 and 5, and the curves W and N of Figure 7.

This conclusion confirms the statement that the visible color of the skin exerts no influence on its absorbing power in the infrared (5).

In the wavelength region below 600 mμ the relative spectral reflectance values spread considerably. This seems to indicate that the

additional pigmentation("driver's tan" on the outside left arm) causes a greater change (decrease) of reflection on the white skin than on the negro skin. This could mean that pigmentation added to a low primary pigmentation (as in the white skin) causes a greater decrease of reflection, whereas pigmentation added to an already high level of primary pigmentation (negro skin) results in a smaller decrease of reflection. Whether or not, and if so how, a saturation phenomenon enters into this problem, cannot be stated at this stage.

In the wavelength region, 560 to 600 mμ, the curves 1 and 2 in Figure 6, and the curves W and N in Figure 7 cross and show an irregularity in direction. This can be ascribed to the fact that the reflection minima due to the absorption by oxyhemoglobin (542 and 576 mμ) and by reduced hemoglobin (556 mμ) are of stronger influence upon the reflectance in this region, than the melanin pigmentation.

Since, in the present phase of the investigation, no attempt was made to determine quantitatively, or even to estimate the amount of radiant energy which caused the additional pigmentation ("driver's tan"), and the time-intensity relation of the exposure, nothing can be said about the relation to the additional pigmentation. The exposure, in the case of the "driver's tan" could be characterized as protracted-fractionated. Very little is known from the literature about the comparative radiation sensitivity of the white and the negro skin with regard to pigmentation. One case has been described where a negro skin has required about ten times the amount of ultraviolet energy to produce the same erythema as that of a white subject (4). In this case a faster and heavier pigmentation was observed on the negro skin. Whether or not a thicker stratum corneum in the negro skin is the cause of the different reaction, as was suspected in the past, has not yet been decided conclusively.

It can be expected that in a further study of the problem the application of known amounts of radiant energy under given time-intensity conditions may yield helpful information. In addition, an extension of the reflectance measurements beyond the present limit of 1 μ to about 3 μ may yield quantitative results which would reveal the absorptive properties of the living skin towards thermal radiation in that wavelength range.

IV. SUMMARY

The spectral reflectance of the human skin was measured over an extended range from 430 to 1000 mμ on a large number of white and negro subjects under varied tan conditions; the results were evaluated statistically. The maximum reflectance was found between 720 and 820 mμ on the least tanned white skin; it is shifted towards greater wavelengths with increased pigmentation; on the heavily tanned negro skin it was found at 900 mμ. Two reflectance minima, probably due to water absorption bands were found; a flat one near 760 mμ which becomes masked progressively with increased pigmentation; the other one at 980 mμ which is strongly pronounced but only slightly influenced by the degree of pigmentation. The difference in spectral reflection of untanned and tanned skin as well as of white and negro skin tends to disappear with increasing wavelength.

V. RECOMMENDATIONS

Reflectance measurements and their evaluation should be extended beyond 431 mμ into the ultraviolet range on one hand, and beyond 1000 mμ into the infrared on the other hand.

The meaning of the present data with regard to the absorption of black-body radiation should be examined.

Other parts of the surface of the human body should be studied.

The effects of known amounts of radiant energy under variation of the time-intensity relation should be investigated.

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TABLE 1

STATISTICALLY COMPUTED SPECTRAL REFLECTANCE (R) AND STANDARD DEVIATION (σ)

Wavelength Mμ	WHITE SKIN						NEGRO SKIN					
	Untanned		Most Tanned		Medium Tanned		Untanned		Most Tanned		Medium Tanned	
	R	σ	R	σ	R	σ	R	σ	R	σ	R	σ
440	19.6	5.8	10.4	4.9	12.5	4.6	5.8	3.1	3.9	2.0	4.3	1.8
460	27.4	6.0	15.2	6.1	16.6	4.8	8.0	4.2	5.2	2.3	5.6	2.2
480	30.4	6.1	17.9	6.0	19.2	4.5	9.6	4.9	6.4	2.6	7.0	3.3
500	33.4	5.5	20.1	6.1	21.6	4.2	11.1	5.3	7.2	3.0	7.9	3.2
520	34.3	5.3	21.6	6.1	22.0	4.2	12.2	5.7	8.2	3.3	8.6	3.5
540	33.1	4.8	21.7	5.7	20.6	4.0	13.0	5.7	8.7	3.3	9.1	3.5
560	34.3	4.9	23.4	5.8	22.2	4.2	14.4	6.0	10.0	3.8	10.3	4.0
580	37.6	5.2	26.6	6.3	24.7	4.8	16.2	6.4	11.2	4.2	11.6	4.4
600	49.3	6.0	36.2	8.0	39.1	5.2	21.1	8.5	14.6	5.8	15.9	6.4
620	53.7	5.9	40.8	8.1	45.3	5.3	24.3	9.1	17.1	6.7	18.6	7.6
640	55.9	5.9	43.6	8.0	48.8	5.4	26.7	9.5	19.3	7.1	20.8	8.2
660	57.8	5.8	47.3	8.2	51.7	5.4	30.0	9.6	22.6	7.5	23.8	8.7
680	59.5	5.6	49.6	7.7	53.9	5.5	32.9	9.5	25.0	7.9	26.6	9.0
700	60.6	5.4	51.6	7.6	55.6	5.4	35.2	9.5	27.7	8.1	28.9	9.4
720	61.2	5.2	53.0	7.1	56.0	5.4	37.9	9.2	30.4	8.1	31.5	9.4
740	60.7	5.0	53.7	6.7	55.6	5.3	39.3	9.0	32.8	8.0	33.8	9.4
760	60.2	5.3	54.4	6.4	55.5	5.4	41.7	8.3	34.5	8.2	35.4	8.8
780	61.0	5.1	55.8	6.3	55.5	5.4	43.7	8.0	37.3	7.8	37.6	8.5
800	61.3	4.6	56.8	6.0	55.3	5.7	45.6	7.7	40.0	7.4	40.1	8.8
820	60.6	4.7	57.0	5.8	54.5	5.3	46.7	7.2	41.9	7.1	40.9	7.7
840	60.3	4.7	57.0	5.5	53.9	5.3	47.8	6.6	43.3	6.8	41.9	7.2
860	59.8	4.6	56.9	5.3	53.1	5.3	48.8	6.2	44.6	6.2	43.0	6.9
880	58.5	4.4	56.3	5.0	52.3	5.3	49.1	5.8	45.7	6.1	43.7	6.4
900	57.4	4.3	55.6	4.5	51.6	4.9	49.0	5.0	45.5	6.0	44.0	6.0
920	55.7	3.7	54.0	4.0	50.0	4.6	48.5	4.3	46.0	5.8	44.2	5.8
940	53.8	3.9	52.3	3.9	47.9	4.7	47.6	4.2	45.3	5.3	42.7	4.9
960	51.1	3.8	49.0	3.8	43.5	4.0	45.4	4.0	43.5	5.4	40.0	4.3
980	49.8	4.1	47.8	3.6	42.2	4.1	45.3	4.0	42.8	4.9	39.9	4.2
1000	50.3	3.7	48.8	3.7	43.8	4.3	46.3	3.8	44.4	4.9	41.4	4.2

TABLE 2

RELATIVE SPECTRAL REFLECTANCE

Wavelength mμ	OF NEGRO SKIN (WHITE SKIN = 100) Untanned %	Tanned %	OF TANNED SKIN (UNTANNED SKIN = 100) White Skin %	Negro Skin %
440	29.6	37.5	53.1	67.2
460	29.2	34.2	55.0	65.0
480	31.6	35.7	58.9	66.6
500	33.2	35.8	60.1	65.5
520	35.7	38.0	63.0	67.2
540	39.3	40.1	65.5	67.6
560	42.0	42.7	68.2	69.5
580	43.1	42.1	70.7	69.1
600	42.8	40.7	73.4	69.2
620	45.8	41.9	76.0	70.1
640	47.8	44.3	78.0	72.3
660	51.9	47.8	81.6	75.0
680	55.3	50.4	83.4	76.0
700	58.1	53.7	85.1	78.7
720	62.0	57.4	86.6	79.7
740	64.7	61.1	88.4	83.5
760	69.3	63.5	90.4	82.7
780	71.7	66.9	91.5	85.4
800	74.4	70.4	92.7	87.7
820	77.1	73.5	94.1	89.8
840	79.3	76.0	94.6	90.4
860	81.6	78.4	95.1	91.4
880	83.9	81.1	96.2	93.0
900	85.4	81.9	96.8	92.8
920	87.1	85.2	97.0	94.8
940	88.5	86.6	97.2	95.2
960	89.2	88.8	95.9	95.8
980	91.0	89.6	96.0	94.4
1000	92.0	91.0	97.0	95.9

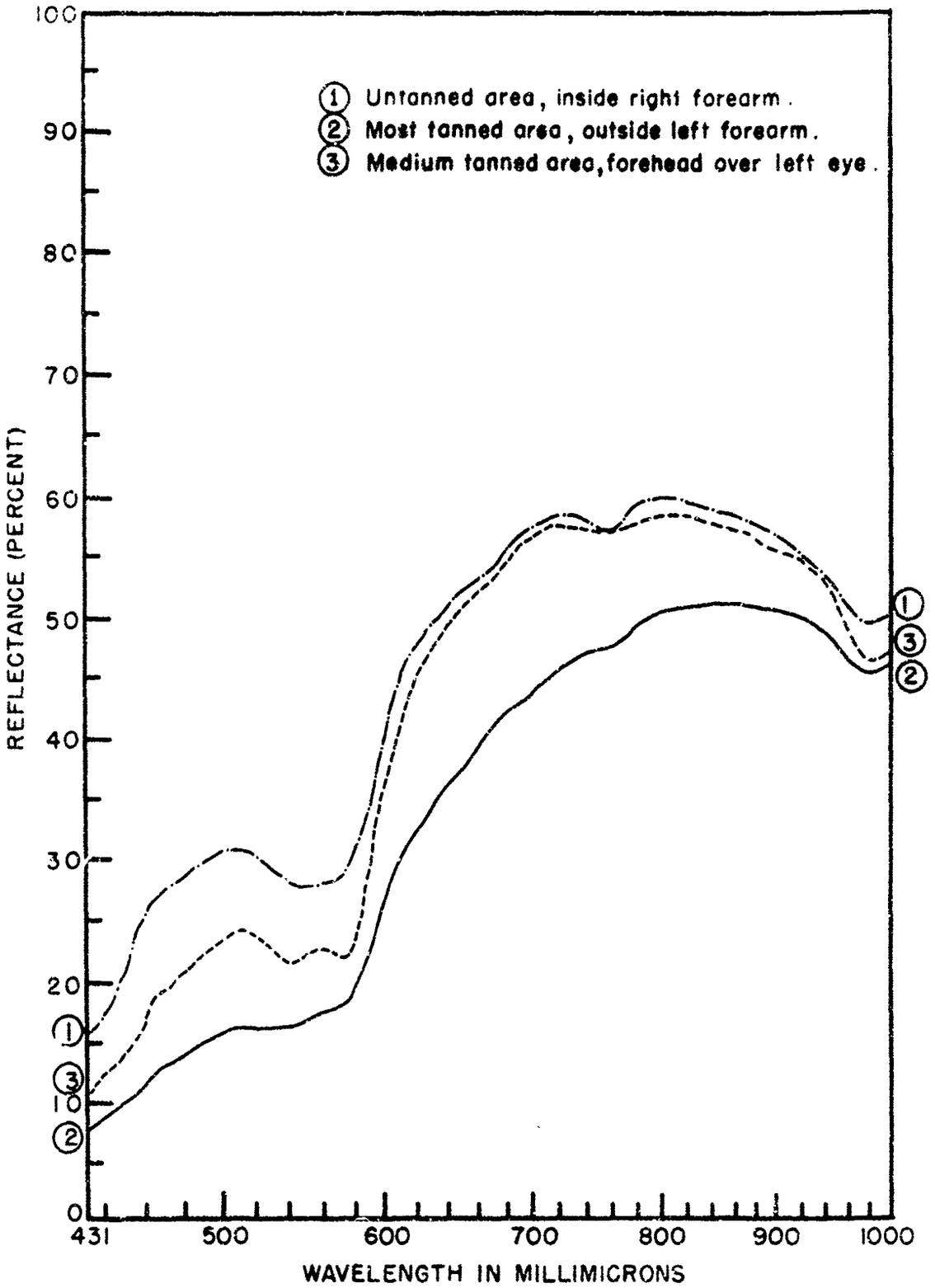

Fig. 1. Spectral reflectance of a white male (subject WM 26).

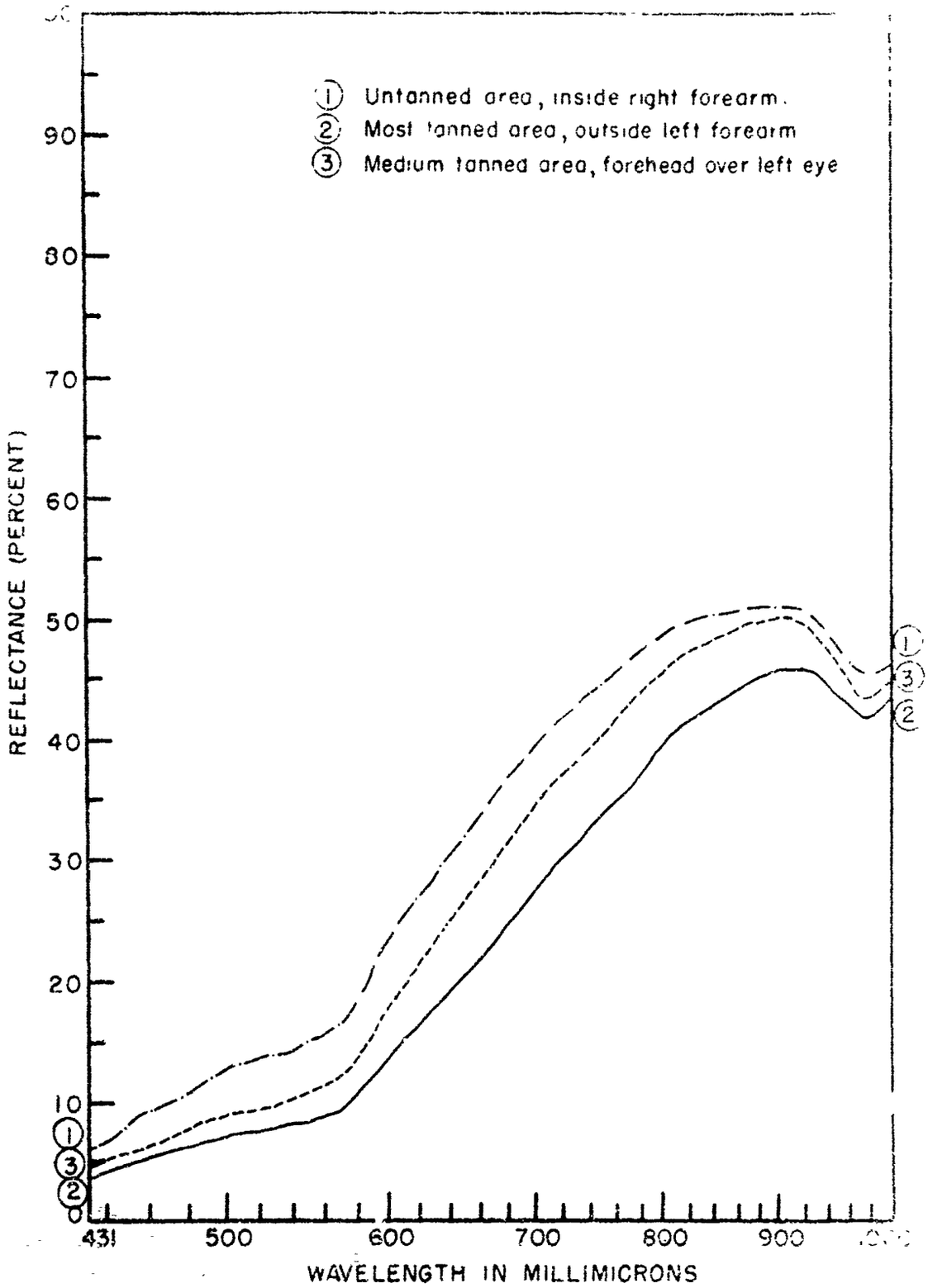

Fig. 2 Spectral reflectance of a negro mole (subject NM 2C)

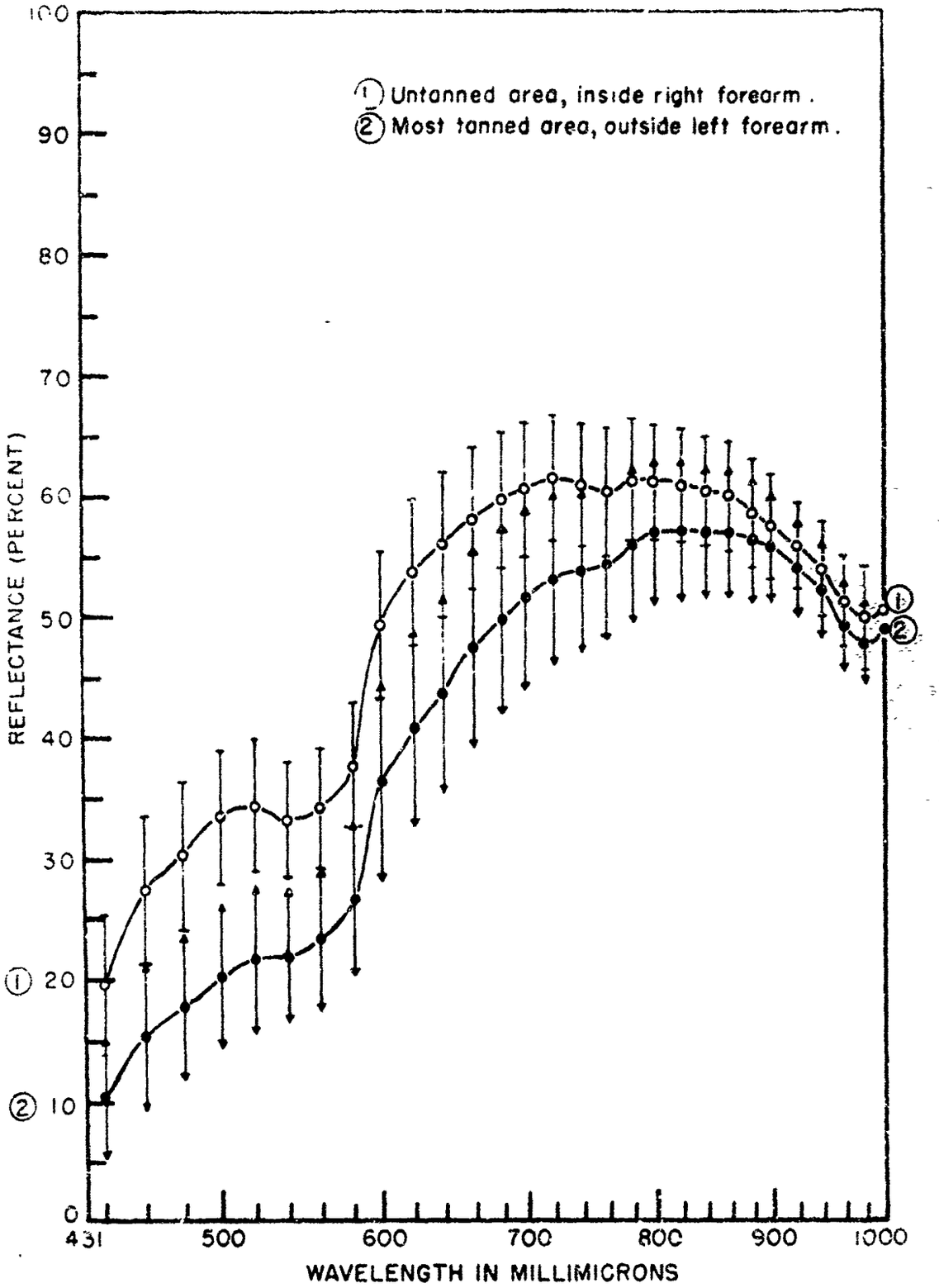

Fig. 3. Average spectral reflectance of 71 white subjects, and standard deviations.

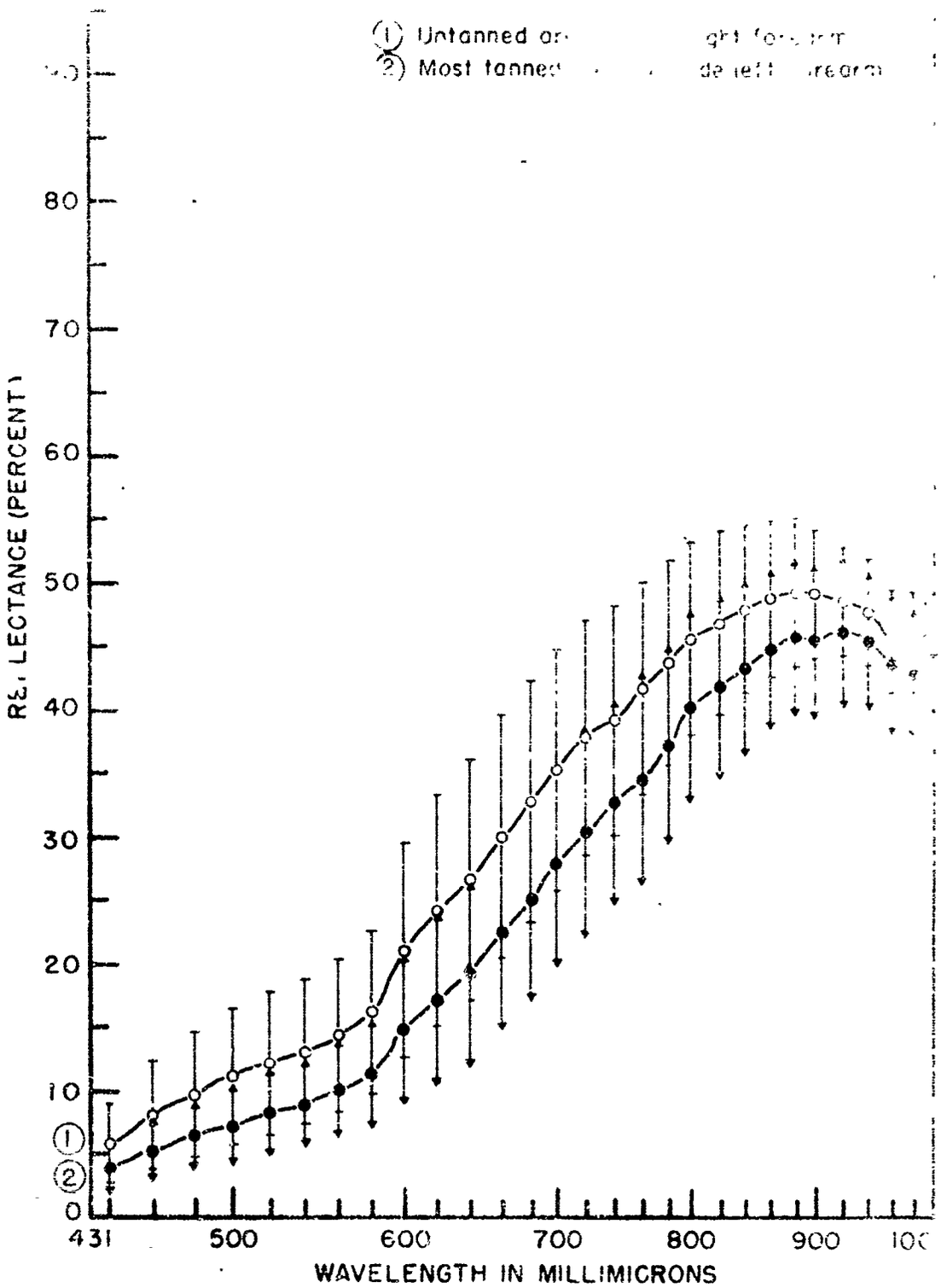

Fig. 4. Average spectral reflectance of 42 negro subjects, and standard deviations.

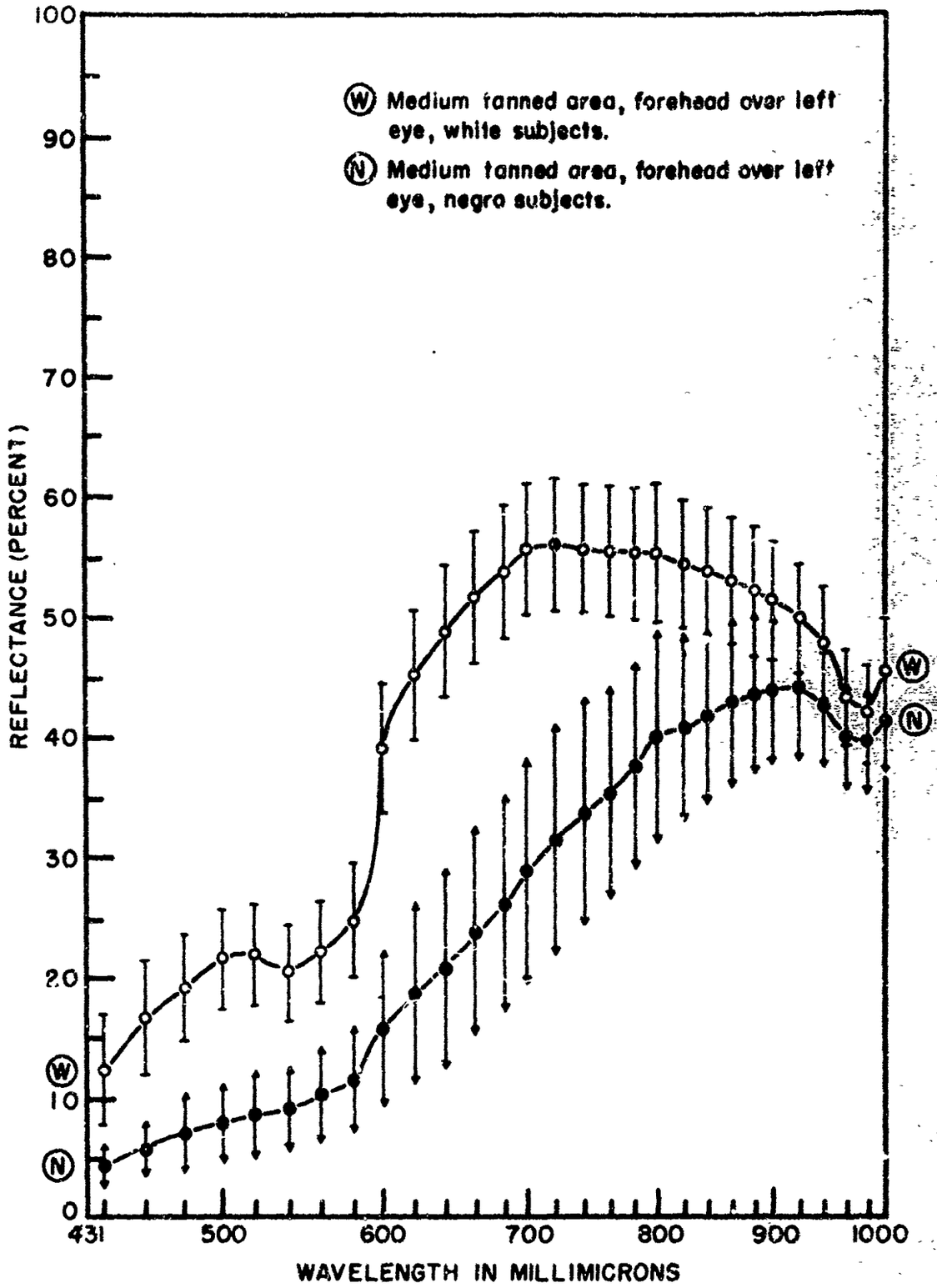

Fig. 5. Average spectral reflectance of 71 white and 42 negro subjects, and standard deviations.

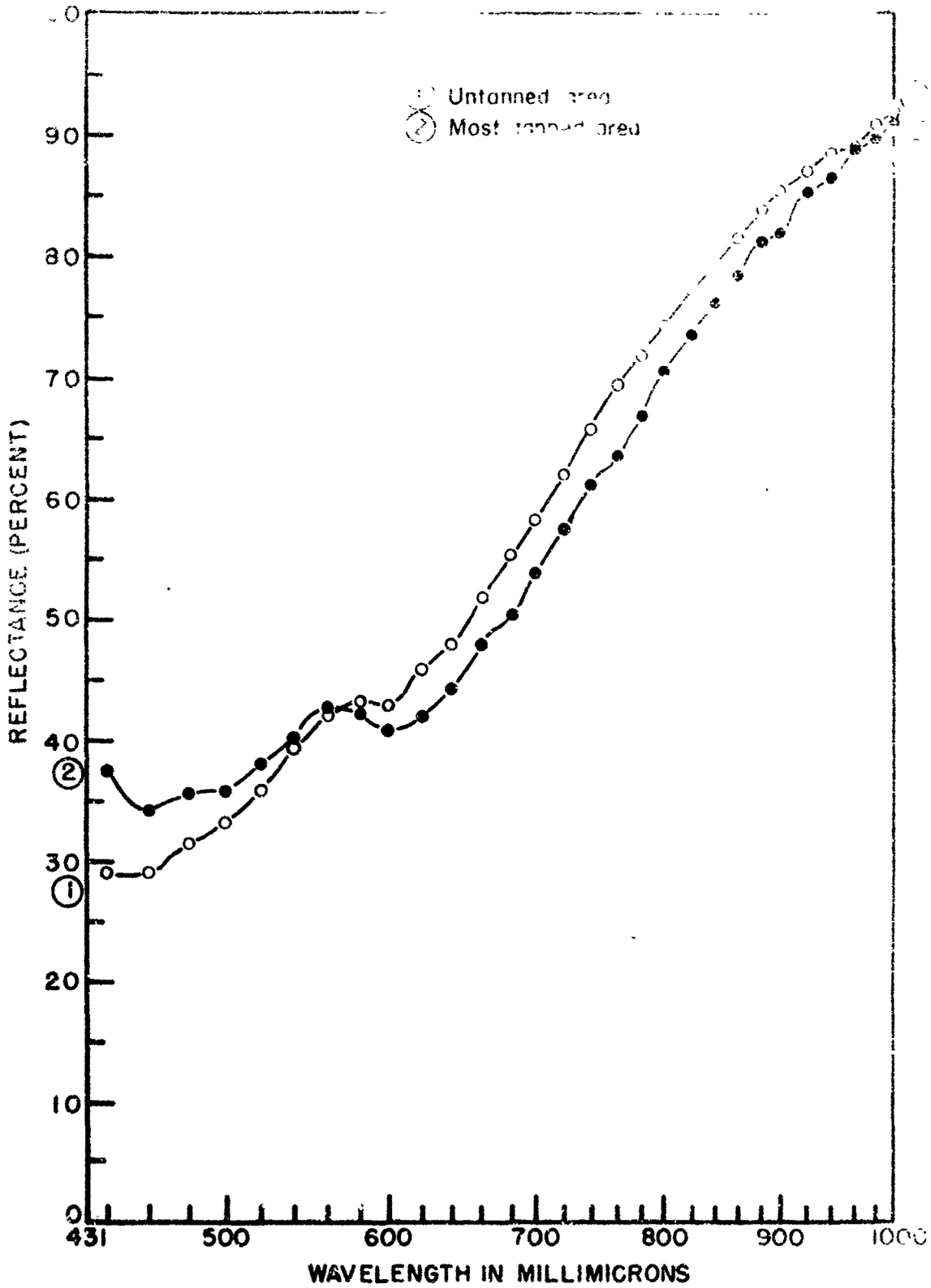

Fig. 6 Average relative spectral reflectance of 42 negro subjects.

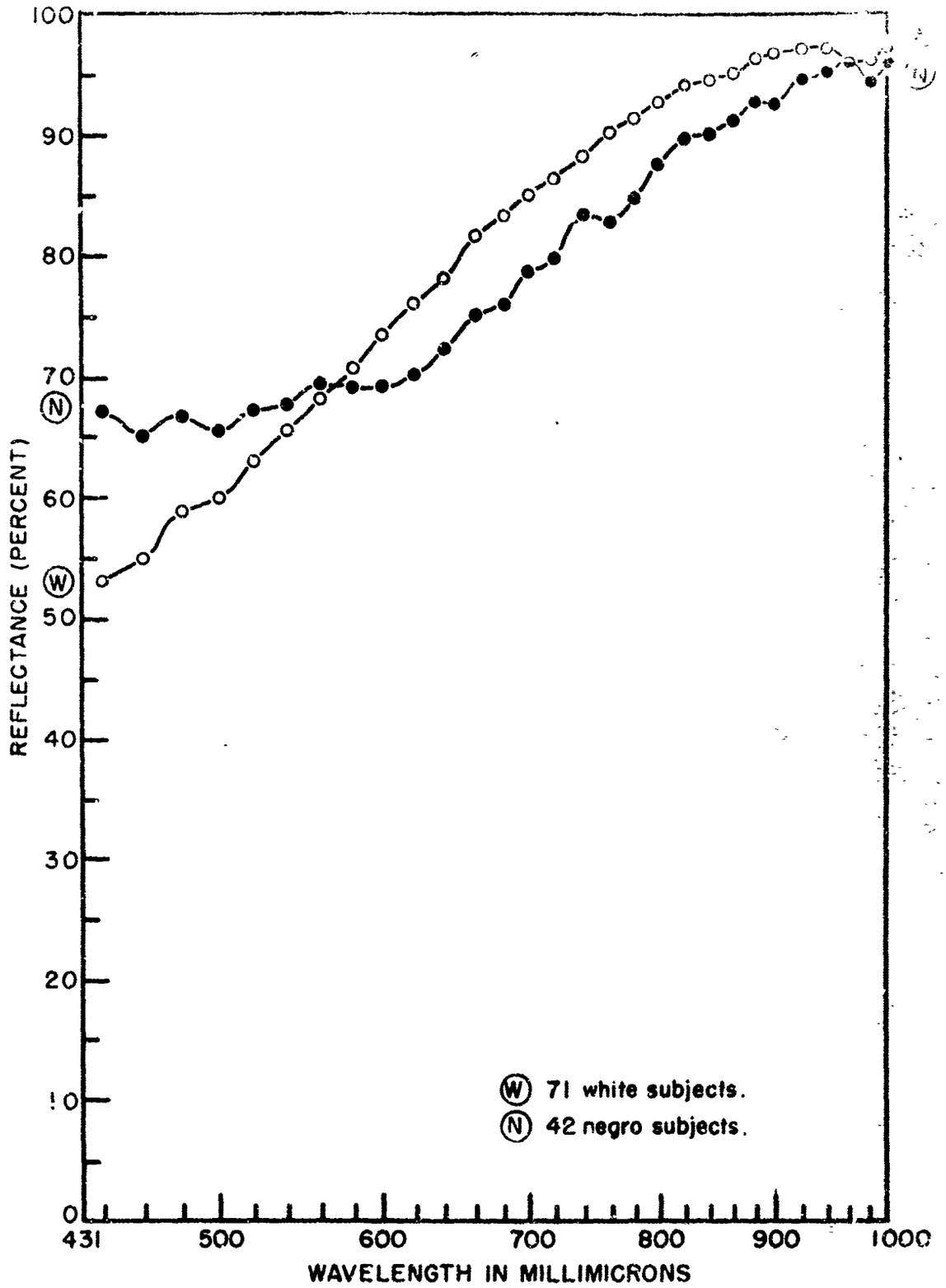

Fig. 7. Average relative spectral reflectance of the most tanned area of 113 subjects.