SKIN COLOR: AN EXAMPLE OF HUMAN ADAPTATION

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Introduction

There are a number of human morphological characteristics which have been interpreted by various investigators as adaptations to natural environment by man. Natural selection probably favors certain types in a population for a given environment and these types may be more fit for their environment. Examples of possible adaptations are: weight (Roberts 1953), skin color and body form (Baker 1958a), and metabolic rate (Roberts 1952).

It has been proposed by various investigators (Barnicot 1959; Harrison 1961, among others) that dark skin has a selective advantage in certain environments. Examined in this paper is evidence for possible skin color adaptation in relation to sunburn, heat stress, production of vitamin D and skin cancer. The geographical distribution of skin color is also discussed.

The Nature of Skin Color

The nature of skin color is today understood fairly well. Edwards and Duntley (1939) found there were four types of pigment: melanin, melanoid, haemoglobin and carotenoid. A scattering effect produced mainly by the stratum corneum influences skin color also. However, the most important of these factors is melanin. Melanin is responsible for producing the variety of skin colors which provide the most striking of racial differences in populations. The importance of melanin in determining skin color is agreed on by Blum (1961:50) and Harrison (1961:99-100). In white skin the amount of melanin present is small and it is only found in the epidermis and may also occur in considerable amounts in dermal cells (Harrison 1961:100).

All people have the ability to tan except albinos. With exposure to sunlight it is widely observed that in time the visible color of the skin darkens. The reasons for this are several: a photochemical reaction begins when wave lengths of .32 microns or shorter are absorbed into the skin. This brings about changes in the nucleoproteins which result in injury to the epidermal cells with the eventual production of new melanin by specialized cells called melanocytes. Melanin already in the epidermis is darkened or oxidized by the introduction of wave lengths in the .30 micron to .44 micron range. The reaction is specific only for these wave lengths. The darkening of skin color is consequently two processes involving the production of new melanin and the darkening of existing melanin (Carruthers 1961:62-67; Blum 1961:51, 55).

Skin color is genetically inherited and Stern (1953) proposed that the mode of inheritance was between four and six gene pairs. However, little work has been done on this aspect of skin color. Also, compared with differences between populations, the variation in skin color within any one population is very small (Harrison 1961:105).

Ultraviolet Radiation and Sunburn

It is often stated that dark skin protects against the injurious effects of ultraviolet radiation. This was first proposed by Finsen (1900) and later challenged by Guillaume (1926) and Miescher (1930). They believed the real protective factor was increased corneum thickness, not melanin. Thomson (1955) obtained samples of stratum corneum by blistering the skin of Europeans and Africans with catharides. He found upon exposing these samples to ultraviolet light that the African's skin was strikingly opaque compared to the Europeans. However, the mean thickness of the stratum corneum of the Europeans and Africans was not significantly different. (The difference between the mean was 1.6 microns and the standard error was ± 0.84 microns.) However, Thomson asserts that corneum thickness is significant but there are other factors (presumably melanin) involved in reducing the transmission of ultraviolet light in the African's skin.

Blum (1955) considered that most of the ultraviolet light was absorbed by the stratum corneum and that variations in the thickness of this layer rather than in the amount of deeper-lying melanin pigment was the main protective factor.

Barnicot (1959:121-122) in reviewing both Blum (1955) and Thomson (1955) observes that it has not been adequately demonstrated that dark skin has a thicker corneum and that melanin may provide significant protection for the living cells of the Malpighian layer of the skin.

Blum (1961:56) again asserts the importance of corneum thickness (citing Thomson 1955 as proof) in protection from sunburn; however, he also points out melanin may play a considerable protective role.

Garn (1964:427) states that having darker skin is potentially adaptive. He points out that exposed and unexposed regions of the body differ in their melanin content and they do so to protect the injurious effects of ultraviolet penetration. He also states that individuals with the piebald condition (nonuniform pigment distribution) develop irradiation erythema (the reddening of the skin due to capillary action upon exposure to ultraviolet light) far more rapidly on the unpigmented areas than in the adjacent areas of normally pigmented skin.

Washburn (1964:1137-1144) in replying to Garn (1964) states Garn has not interpreted Blum (1961) correctly since he has not mentioned the importance of increased corneum thickness as a protective factor. It is also pointed out that Blum asserts that sunburn protection only lasts as long as the corneum is increased in thickness. Skin color may remain darker than before ultraviolet exposure but the protection is only good for as long as the corneum is increased in thickness which is a much shorter period of time.

There seem to be two effects by which radiation damage is reduced. Melanin provides an important primary protection, but increased thickness of the stratum corneum may also be involved. However, the nature of the primary source for the latter hypothesis, Thomson (1955), is not at all conclusive on this point.

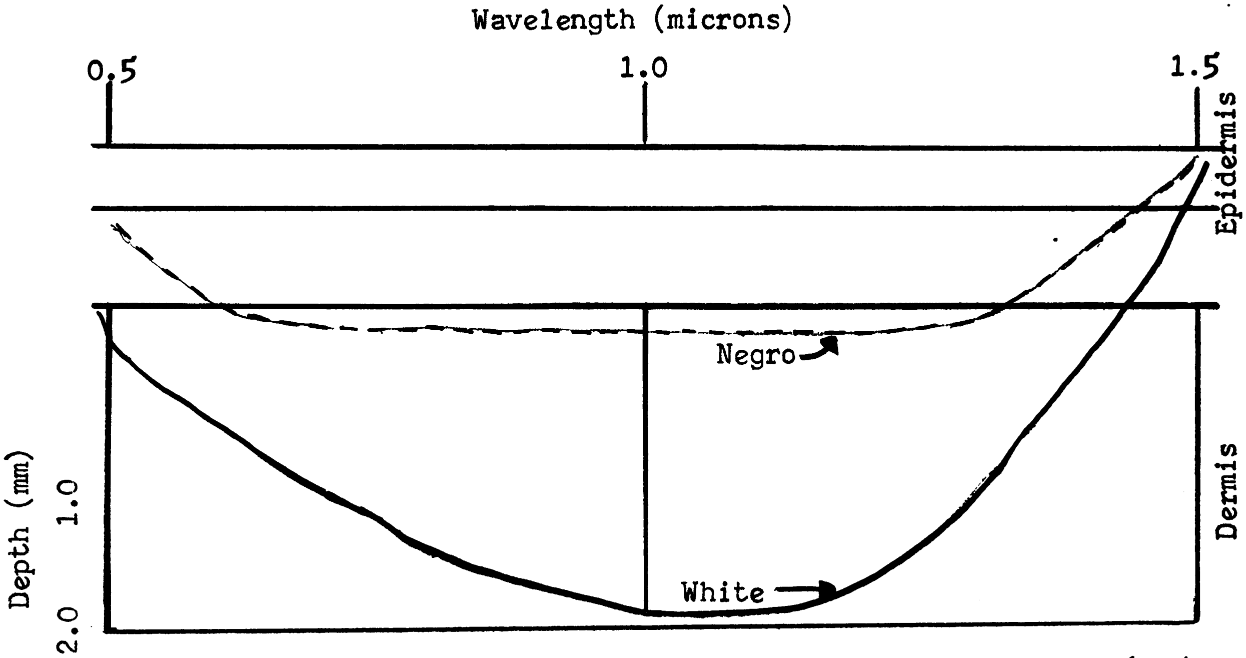
The Reflection and Absorption of Sunlight

It has been established that dark skin absorbs more sunlight than white skin. Baker (1958b) in studying American Negroes and whites found whites absorb 69.7 percent of the incident light and Negroes absorb 84.6 percent (mean values for 40 matched pairs of subjects). Heer's work (1952) with Europeans and Negroes showed that Negroes absorb up to 34 percent more thermal energy (incident sunlight) than Europeans. However, the absorption or reflection of sunlight is a function of wave length as the following graphs show.

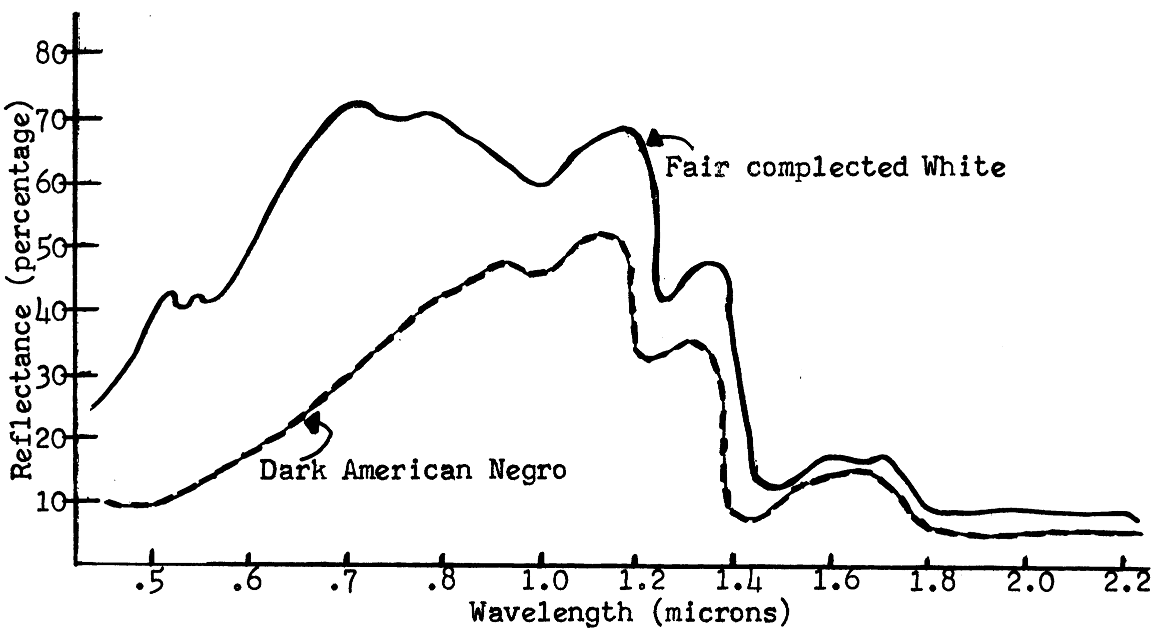
In Graph I the difference in penetration of sunlight can be seen for Negro and white samples. The effect of melanin and perhaps corneum thickness is very apparent. Graph II shows that white skin reflects as much as 70 percent of the incident light for some wave lengths. Also, there is a significant difference in reflectance over the visible spectrum of light.

The question which now has to be answered is what is the effect of this increased heat load on man? Heat load or stress due to absorbed energy has been difficult to define. The observed reactions to heat stress are increased rectal temperature, increased sweating and increased pulse beat. Baker (1958b) conducted studies of heat stress on American Negroes and whites under hot-wet and hot-dry conditions. Under hot-wet conditions the Negroes showed a higher heat tolerance as can be seen in Table 1. Under hot-dry conditions a different situation was observed. A strong difference between Negro and white occurred in the "sun-nude-rest" condition (Table 2). It was found that there was a difference of almost four-tenths of a degree Fahrenheit in the rectal temperature of Negroes compared with the whites in the most extreme case. When the Negroes were protected from the sun, their rise in rectal temperature was the same or even lower than that of whites. Using the technique described in the article it was calculated that Negroes (under the extreme condition of sun-nude-walk) absorb 110 kg. Cal. more than whites. According to Baker's calculations the Negro should have evaporated 190 more grams of sweat than the white in order to keep thermoregulation. However, as shown in Table 2 this much sweat loss difference was not observed. Baker concluded that Negroes were able to dissipate more heat than whites without a proportionately greater sweat loss. Baker infers that this was possible because of a higher skin temperature in Negroes, but this was not determined empirically. However, his idea seems reasonable. If the skin temperature was higher then the difference between skin temperature and environment temperature would be less. Consequently, with a smaller temperature differential than expected (using white skin as a comparison) less sweat than theoretically calculated could be expected.

These mechanisms for dissipating heat aid in preventing the core temperature of the body from changing. It is important that the core temperature remain stable or death may occur (Baker 1958a:85). When skin temperature starts rising and the heat is not dissipated then a serious situation is present. Increased sweating and temperature reflect the attempt by the body to dissipate this heat. If (as under the hot-dry condition) the Negro sweats more and his temperature increases then he is under greater heat stress than the white. I shall return to the question of dark skin and whether or not it is an adaptation to hot-dry or hot-wet conditions later in this paper.



GRAPH I Blum 1961:52



GRAPH II Barnicot 1959:121

TABLE 1

Measurement	White Mean	n = 40 s.d.	Negro Mean	n = 40 s.d.	Mean Diff.	Significance of Difference
Pre-test Rectal Temperature °F	99.6	0.38	99.4	0.42	0.2	0.05
Post-test Rectal Temperature °F	100.4	0.45	100.0	0.45	0.4	0.01
Pulse rate Beats/min.	122.4	12.9	119.4	14.6	3.0	0.05
Sweat loss Grams/hr.	912.	139.	873.	137.	39.	0.05

This table is a comparison of American white and Negro heat stress under hot-wet conditions.

Experimental conditions: nude walk

Source: Baker 1958b:292.

TABLE 2

Group	Sun Nude Walk	Sun Nude Rest
Comparison of Total Sweat Loss (in grams)[a]		
Negro	2,796	2,010
White	2,656	1,857
Difference	- 140	- 153
Comparison of Rectal Temperature (°F)[b]		
Negro	100.40	99.54
White	100.02	99.30
Difference	-0.38	-0.24

This table is a comparison of American white and Negro heat stress under hot-dry conditions.

[a]Baker 1958:299.

[b]Baker 1958b:297.

Conducting experimentation on blackened and unblackened skin Wright (1958) found the following results: higher intensities of light were required on unblackened skin to produce the same temperature sensation as that produced on blackened skin at lower light intensities. In other words, blackened skin possibly has a lower temperature threshold, i.e. reacts to thermal energy quicker. This observation is completely in line with the material already presented. If dark skin absorbed more of the incident light, then it would be expected that this increased absorption would produce a proportionately lower heat threshold sensitivity.

Vitamin D Production and Melanin

The same wave lengths of light that produce sunburn also are instrumental in producing vitamin D. The general assumption is that 7-dehydrocholesterol originates from cholesterol in the skin and is further transformed into vitamin D by ultraviolet irradiation (Carruthers 1962:79). One of the chief functions of vitamin D is the maintenance of the normal processes of bone formation. Lacking the required amounts of vitamin D rickets occurs. This often results in severe damage to the skeletal structure (Wilson 1960:199).

However, Blum (1961:57) discounts the role of sunlight in vitamin D production because of its presence in the diet. But vitamin D is fat soluble and is present chiefly in fatty foods. The main source of vitamin D is animal protein and especially liver (Bowes 1956:8-61). Various food products have vitamin D added to them but we are not concerned with this source of vitamin D in this paper. Much of the native population of the world probably obtains vitamin D as a result of the action of sunlight on the skin. It is interesting to note rickets normally does not occur in the tropics (May 1958:5).

The location of 7-dehydrocholesterol is primarily in the Malpighian layer of the skin, but traces occur in the stratum corneum (Carruthers 1962: 76). The presence of concentrations of melanin in the epidermis scatter and absorb much of the incident ultraviolet light and hence have an effect on the production of vitamin D (corneum thickness may also be of importance). This effect could well be to limit the production of vitamin D. This hypothesis is possibly in line with the toxic effects of excessive amounts of vitamin D in the body (Reed 1939:151). No researchers have reported hypervitaminosis D due to ultraviolet light exposure and it would seem one possible reason for this is presence of melanin and its ability to control to some extent the production of vitamin D.

This relationship between vitamin D and melanin is further substantiated by two interesting observations. Massage of the skin previously unexposed to ultraviolet light with ointment containing vitamin D produced considerable pigmentation of the skin. Also, it was noted in two instances when vitamin D was ingested over long periods of time pigmentation increased. When treatment was discontinued the increased pigmentation disappeared (Reed 1939:4-5). It appears there is some relationship between increased pigmentation (production of new melanin) and production or absorption of vitamin D. While no clear-cut explanation is present in the literature the hypothesis presented is interesting. Garn (1961:56) has also used this hypothesis.

Skin Cancer and Melanin

The same wave lengths which are instrumental in producing vitamin D, melanin, and sunburn, also produce skin cancer. These skin cancers occur on exposed portions of the body, particularly the face. While widely reported for white skinned people their occurrence is very rare in dark-skinned people (Blum 1955, 1959). These skin cancers are usually not lethal and consequently their survival value for adaptation could not be great. However, it is another interesting characteristic of melanin in the skin. Although Blum again argues that thickness of the stratum corneum rather than melanin is the principal protective factor.

Geographical Distribution and Skin Color

The test of any hypothesis is how well it explains most of the observed phenomenon. Of the ideas on skin color mentioned two hypotheses lend themselves to experimental verification. The first is the relationship between sunburn protection and dark skin. The second is whether or not dark skin is an adaptation to a hot-dry climate or a hot-wet climate. Fleur (1945) made a study of the distribution of skin colors around the world (except the New World) and produced a map of skin color distribution. This map has been used by researchers to prove their theories and to disprove the theories of others. Fleur and later Thomson (1955:237) felt there was a meaningful pattern in skin color distribution, i.e. dark-skinned people are found in regions where ultraviolet radiation is the most intense. However, there are exceptions of which the major one is the distribution of skin color in the New World.

Criticism of this correlation between skin color and sunburn protection has come from Blum (1961) and others. Washburn (1964) suggested that the face color in monkeys and apes did not correlate in any simple way with the environment. He also suspects this to be the case in man. Richards (1952) made a study of ultraviolet radiation level in the Congo and suggested that the level of ultraviolet radiation at ground level was no higher than in Western Europe. He cited as reasons for this the presence of a leaf canopy, water vapor, and volcanic dust in the atmosphere acting as an ultraviolet filter. The Congo presented a problem. There was a large population of people who had dark skin but were not under intense ultraviolet radiation.

There are two distinct local races living in the Congo which appear to be adapted to two different natural micro-environments and to be different in their immediate racial histories. The Bantu of Central Africa and the people of West Africa have a long tradition of being agriculturalists and living in villages. In discussing the culture area of West Africa, Forde (1953:124) states "The forest people were and are cultivators depending basically on root crops, yams (<u>Dioscores</u>), and cocoyams (<u>Calocasia esculenta</u>), and fruits, especially varieties of the cultivated banana (<u>Musa spp</u>)." He also states that these local communities consisted of several hundred to several thousand individuals who live in cleared village areas.

In contrast to the agricultural Bantu, who stem from the same cultural tradition as the West African as suggested by Greenberg (1959:20), are the Pygmies of the Congo. The Pygmies (except for those who have been acculturated) are a hunting and gathering people. They live in the forest and only occasionally come into the Bantu villages. The Pygmies have the protection of a leafy canopy in the forest, but the Bantu villagers live in cleared areas and are exposed to more intense solar radiation. There is an interesting example of what happens when Pygmies are forced to work out in the open. Turnbull (1962:271-272) describes an attempt by the local Belgian administrator to force Pygmies to clear land and start agricultural work out in the open: ". . . the Pygmies are not able to stand the direct sunlight and become ill outside the shade of the forest . . . on one small model plantation where the Pygmies were being liberated 29 died on one day from sunstroke." It has also been noted that Pygmies skin color is lighter (reddish yellow) than the Bantu who live around them (Turnbull 1963:38).

It therefore seems possible that the Bantu are more adapted to work in open clearings than the Pygmies. Also, the heat stress is greater in open clearings than under a leafy canopy. Landell (1955) states that a cleared site in the forest zone of West Africa near Lagos had a Vernon Black globe temperature that was on the average 20°F above the ambient air temperature. Consequently, it is possible to suggest that the Bantu of the Congo do not present the problem to geographical correlation of skin color which Richards (1952) suggested. It would appear Richard's study would apply more to the Pygmies than to the Bantu.

Other possible explanations to the distribution of skin color in the Congo are offered by Harrison (1961:110-111). He suggests first that heavy pigmentation may be ancestral to the species and no selective pressure has operated to change it. Second, the inhabitants of the Congo may be recent immigrants from neighboring savannas as Greenberg (1959:20) has suggested. Or third, it is possible that some other quite different selective force is operating.

Concerning the second hypothesis that dark skin is an adaptation to a hot-wet instead of a hot-dry climate, the following comments apply: Baker argues that dark skin is under higher heat stress in a hot-dry climate than lighter skin. He has also pointed out that dark skin seems to be more adapted to a hot-wet climate. To support these ideas he cites the fact that most dark-skinned people live in a tropic or semi-tropic area which he calls a hot-wet climate. With the exception of the tribes in the South Sudan (Dinka, Nuer, etc.) who are among the darkest in Africa and the Australian Aborigines, his hypothesis has a reasonable geographical correlation. Baker points out that it is easier to hypothesize migration from the tropics to the savanna and semi-desert zones than to do vice versa. Considering both of the hypotheses it seems, with exceptions, that the distribution of skin color which would be expected is indeed the one which occurs.

Conclusion

Dark skin may have multiple beneficial functions serving populations. It probably protects from sunburn, skin cancer, and is likely related to vitamin D production. However, dark skin may cause a greater heat strain in the individual because of greater heat absorption. In the case of skin cancer, sunburn protection, and vitamin D, these are all examples of possible selective pressures. Considering that sunburn or heat stroke could be a serious problem in a small population where every producing member was crucial and that this could have characterized mankind up until only the last few thousand years, an adaptation reducing the possibilities of this occurring seems beneficial in making the population fit for its environment. However, in the case of dark skin the positive advantages might be offset by the adverse effects of higher heat stress. Dark skin may have minimized these adverse effects by having a higher skin temperature than white skin although this needs to be determined empirically. In short, there are a number of positive and negative factors (many perhaps unknown today) which determine the particular color of skin the larger percentage of a population is going to have. Natural selection operates on all the available avenues for adaption of a population to its environment. In view of the evidence presented, skin color can certainly be counted as one of those characteristics of man which has potential adaptive value for certain environmental situations.

Further research is clearly needed to establish the survival value of the above mentioned characteristics of dark skin and more work is needed on the relationship between vitamin D and melanin. It has also been shown that the primary source on increased corneum thickness (Thomson 1955) is not conclusive although other researchers have accepted his hypothesis seemingly without much question. New experiments on the racial difference in corneum thickness are needed to resolve this question.

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