NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

A Rainbow of Sepia: The Evolution of Human Skin Color*

by

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Part I – Why Are People Different Colors?

Nina Jablonski, a biological anthropologist at Penn State University, spent many hours thinking about "the sepia rainbow of human skin color." She knew that our closest primate relatives have pale skin under dark fur, but human skin comes in a variety of shades from pinkish white to dark brown. How did this variation arise?

Many biological traits have been shaped by natural selection. Could human skin color be one such trait? If so, she would have to find the selective pressure that caused different populations to evolve varying levels of skin pigmentation.

You will now meet Nina in a brief video clip (**https://www.hhmi.org/biointeractive/biology-skin-color**). She will take you on a journey that she undertook in the pursuit of this question. After you view the video, answer the following five questions. (Watch until 5:49 min, "Is there a link between the intensity of UV radiation and skin color?")

Questions

1. Describe the conditions necessary for evolution by natural selection to take place in a population.

2. With regard to the evolution of skin color in humans, which of these conditions is Nina sure about (and why?) and which one(s) is she investigating?

3. What is Nina's likely hypothesis about the evolution of skin color in humans?

4. If her hypothesis is correct, predict the characteristics of the environment where the most heavily pigmented human populations are likely to be found, and the environment where the least pigmented human populations will be found.

5. How might she test her hypothesis?

*Adapted from:

- Prud'homme-Généreux, A 2011. The evolution of human skin color: a case study. National Center for Case Study Teaching in Science. <http://sciencecases.lib.buffalo.edu/cs/collection/detail.asp?case_id=584&id=584>.
- Bonetta L, M. Csikari, and S. Keep. 2015. Human skin color: evidence for selection. HHMI BioInteractive. <http://www.hhmi.org/biointeractive/human-skin-color-evidence-selection>.

Part II – Is UV Radiation Linked to Skin Pigmentation?

Nina has a hunch that melanin evolved in our skin to protect us from the sun's harmful UV radiation, and that the most heavily pigmented human populations have evolved in areas of high UV intensity. This can account for the variability in human skin pigmentation only if different populations are exposed to different levels of UV light. Is there evidence that the amount of UV light varies across different environments on this planet?

Nina asked her husband, Penn State University geographer George Chaplin, for help. At her request, he created a map showing the UV Index, a standardized scale that forecasts the intensity of UV radiation at any given time and location on the globe. Figure 1 shows an example of a similar map to the one George created.

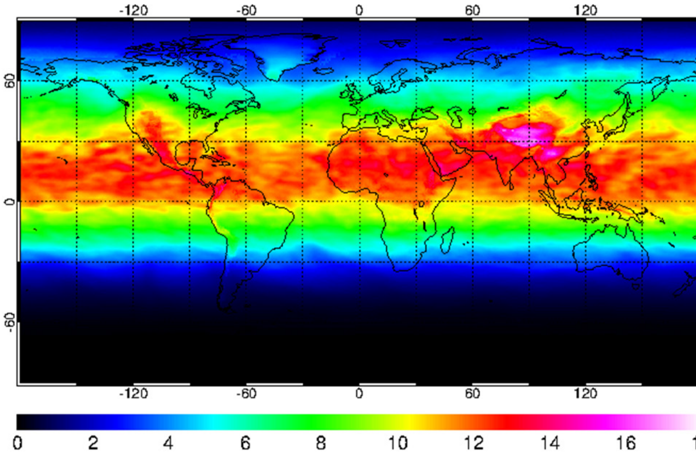


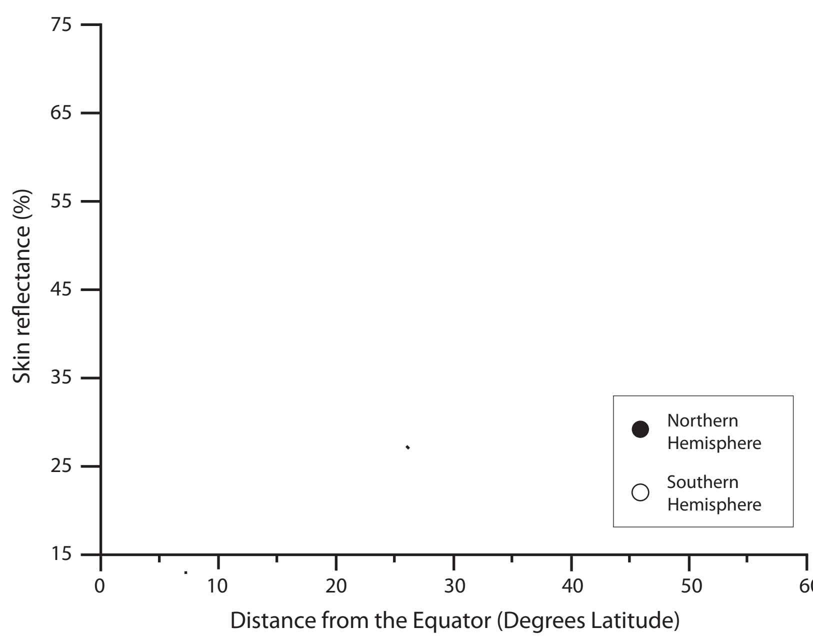
Figure 1. UV Radiation Index across the World. Recorded on July 15, 2017, this map shows the amount of UV light reaching the Earth's surface throughout the world. The legend at the bottom indicates that reddish areas receive the greatest amount of UV radiation and blue areas receive the least. (*Source:* European Space Agency, <http://www.temis.nl/uvradiation/UVindex.html>.)

Questions

1. Describe the pattern of UV variability across the globe.

2. If Nina's hypothesis is correct, where on this map do you expect to find the most heavily pigmented human populations? Would it be in Brazil, Greenland, Europe, India, or Australia?

3. Using the graph provided, plot the data Nina expects to find. Each data point represents a human population. The X axis shows how far away from the equator the population lives. The Y axis captures the skin pigmentation of the population. Note that this data is recorded as "skin reflectance," which is a measure of skin lightness (i.e., high values indicate lighter skin). Two curves should be drawn, one for populations living in the Northern Hemisphere and one for populations in the Southern hemisphere.



Part III – How Does UV Radiation Exert its Selective Pressure?

Nina searched the literature and discovered that another anthropologist had collected data on exactly what she wanted. John Relethford, a Distinguished Teaching Professor at the State University of New York at Oneonta, had searched the literature for information on the skin pigmentation of indigenous men and graphed it against the latitude where the population evolved. The data is shown in Figure 2.

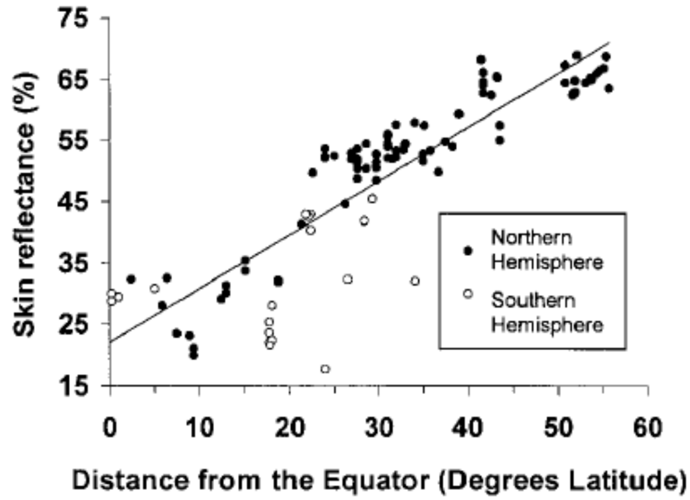


Figure 2. Relationship between skin reflectance and latitude. (*Source:* Relethford, J.H. 1997. Hemispheric difference in human skin color. *American Journal of Physical Anthropology* 104: 449–57. Figure 2. ©Wiley Periodicals, Inc., used with permission.)

Questions

1. Does this graph confirm or refute Nina's hypothesis?

2. Propose a mechanism by which UV radiation exerts a selective pressure on the human population that leads to the evolution of skin pigmentation. Specifically, what is affecting fitness (the number of descendants that an individual contributes to the next generation)?

3. When Nina turned her attention to this question, a leading hypothesis was that UV radiation causes DNA mutation, sometimes leading to melanoma, a form of skin cancer with a high mortality rate. Skin cancer was proposed to remove individuals who did not have sufficient pigmentation in their skin from the population and exert a strong selective pressure for dark skin in high UV areas. But Nina didn't buy it. Why might Nina suspect that this proposed mechanism is not accurate?

Part IV – What Caused the Variation in Skin Color?

Let's continue to watch Nina's story unfold. You will be shown the next portion of the video. This video segment lasts about six minutes (end at 12:19 min, "For that reason, though it might cut your life short, it's unlikely to affect your ability to pass on your genes.")

While Nina felt confident that UV radiation affected the evolution of skin color, she rejected the hypothesis that this was driven by the development of skin cancer. UV radiation must be affecting something else in the body, something crucial that impacts an individual's ability to reproduce and pass on their genes. What could that be?

Serendipitously, around the time that she was asking herself these questions, Nina read a paper in which she found the data shown in Figure 3.

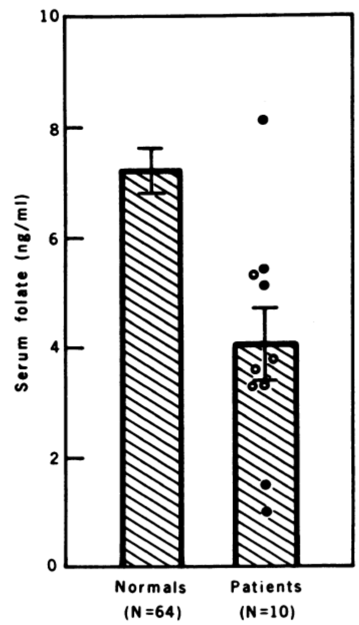


Figure 3. Levels of blood folate depend on exposure to UV radiation.Subjects ("patients") were exposed to UV radiation for 9 hrs every day for 3 months, while controls ("normals") were not exposed, and their blood levels of folate were measured. (*Source:* Branda, R.F., and J.W. Eaton. 1978. Skin color and nutrient photolysis: an evolutionary hypothesis. *Science* 201: 625–6. Figure 1, reprinted with permission from AAAS.)

Folate is a B vitamin found in dark green leafy vegetables, from which it gained its name ("foliage"). In men, this vitamin helps with sperm production, and in women it is essential during pregnancy. Deficiencies can lead to malformation of the baby's nervous system.

Questions

1. Name two ways in which a person could become deficient in folate.

2. Propose a mechanism by which folate influenced the evolution of skin color.

3. If there is a benefit to blocking the sun's UV radiations, why aren't all populations heavily pigmented?

Part V – The Benefits of UV Radiation

Nina will now tell you the story of how she came to the same conclusions you just reached about folate. This is a short two-minute ckip (end at 13:44 min, "Why aren't we all dark skinned?").

Nina realized that the need to protect folate from the damaging effects of UV radiation can explain why dark skin evolved, but it cannot account for the evolution of light skin. Something else must be involved.

Nina knew that UV light doesn't just have damaging effects on the body. It's also something that we need to stay healthy. Our skin uses the energy of UV radiation to synthesize vitamin D. This vitamin is essential for the absorption of calcium from our diet, which in turn is necessary to build strong bones and healthy teeth. Vitamin D has also been implicated in proper immune system functions, a healthy heart, and mental health. In addition to being made in our skin, vitamin D can be consumed in foods such as fatty fish (tuna, mackerel, sardine, and salmon) and egg yolks. Nowadays it is added to foods such as breakfast cereals and milk.

How much UV radiation do people need to stay healthy? Nina and her husband calculated how much vitamin D could be synthesized by individuals of different skin colors living at different latitudes and therefore exposed to different levels of UV. There findings are in Figure 4.

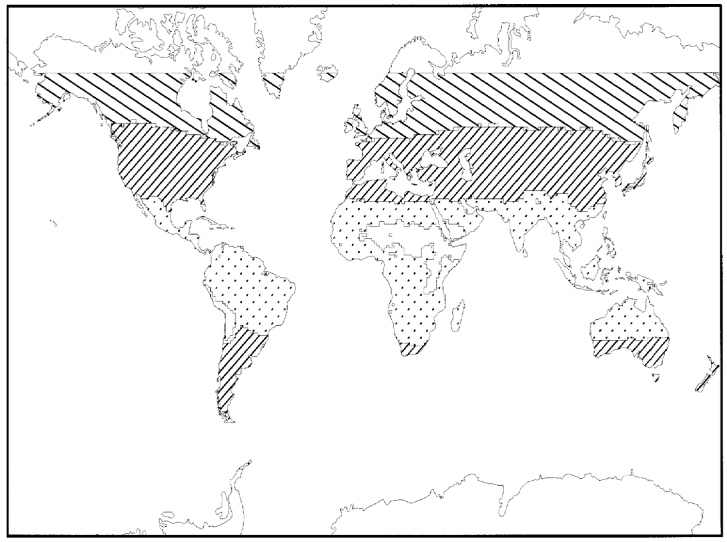


Figure 4. Map showing regions of the world predicted to provide insufficient UV radiation to meet the vitamin D needs of populations with different skin colors. Widely spaced diagonal lines show regions in which UV radiation, averaged over an entire year, is *not* sufficient for vitamin D synthesis by people with lightly, moderately, or darkly pigmented skin. Narrowly spaced diagonal lines show regions in which UV radiation is *not* sufficient for vitamin D synthesis by people with moderately and darkly pigmented skin. The dotted pattern shows regions in which UV radiation averaged over the year is *not* sufficient for vitamin D synthesis in people with darkly pigmented skin. (*Source:* Jablonski, N.G., and G. Chaplin. 2000. The evolution of human skin coloration. *The Journal of Human Evolution* 39: 57–106. Figure 2, reprinted with permission from Elsevier.)

Questions

1. According to Nina and her husband's calculations, which regions of the world allow lightly-, moderately-, and darkly-pigmented individuals to synthesize sufficient amounts of vitamin D from sunlight throughout the year?
2. Do these regions match where these populations evolved?
3. What allows individuals to survive in regions of the world that do not allow them to synthesize sufficient amounts of vitamin D throughout the year?
4. Why are all populations darker than predicted in order to achieve optimal levels of vitamin D from sunlight?
5. Nina and her husband have found that women are consistently less pigmented than their male counterparts in all populations that have been sampled. Propose a hypothesis to account for this observation.

Part VI – What Happens Now?

In the next two-minute video clip, Nina will take you through some of her thinking on vitamin D (end at 16:05 min, when Nina mentions the example of Inuits skin color and the scene fades to white).

What Nina discovered is that the needs to protect folate and to synthesize vitamin D exert opposing pressures on the evolution of skin color. Melanin levels in the skin represent a compromise between these two needs, struck by evolution through natural selection.

After thousands of years of evolution, how well adapted is our skin color? Consider the data in Figure 5, which shows the blood levels of vitamin D in Americans grouped according to age, sex, and ethnic background. Levels between 20–50 ng/mL are considered adequate for health.

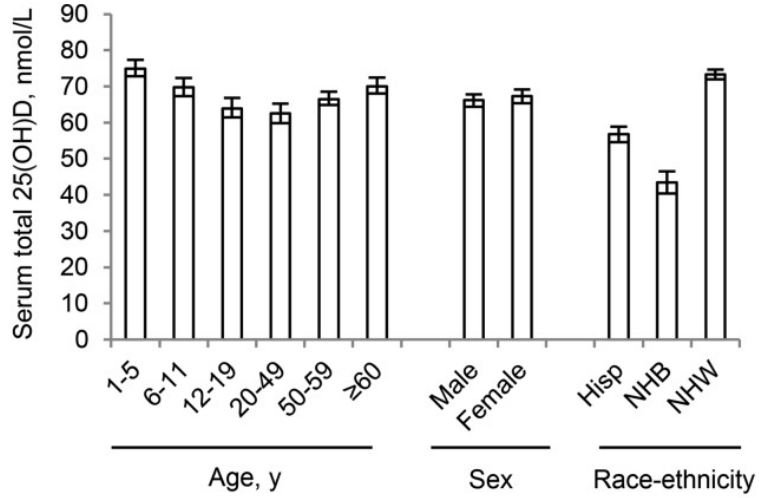


Figure 5. Levels of vitamin D in the blood of Americans. In the race-ethnicity section, "Hisp" refers to individuals of Hispanic background, "NHB" refers to non-Hispanic blacks, and "NHW" refers to non-Hispanic whites. Note that "Serum total 25(OH)D" means the levels of vitamin D in the blood. (*Source:* Schleicher, R.L., *et al.* 2016. National estimates of serum total 25-hydroxyvitamin D and metabolite concentrations measured by liquid chromatography-tandem mass spectrometry in the US population during 2007–2010. *The Journal of Nutrition* 146(5): 1051–61, Figure 1A. Reproduced by permission of American Society for Nutrition.)

Questions

1. How do you explain the differences between ethnic groups in vitamin D levels?

2. Which population is at greatest risk of developing rickets, a disease of vitamin D and calcium deficiency that leads to bone malformation? What can be done about it?

3. For several decades, vitamin D has been added to milk to help increase intake of this nutrient. But in some ethnic groups, this strategy isn't working. Why might this be?

4. Who is most at risk of developing folate deficiency and fertility problems? What can be done about it?

5. Based on what *you* have learned in the case, what actions will you take to maximize your vitamin D and folate levels?

6. Is natural selection still acting on the trait of skin color in human populations? If so, how would you expect human skin color to change in human populations in the future?