

## Review Article

# The colour of the human skin: fruitful science, unsuitable wordings

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## Synopsis

A review of the various facets of the colour of human skin is proposed. It aims first at illustrating the paradoxical association of the remarkable recent scientific advances that characterize changes in the skin colour, with some totally inappropriate or outdated phrasings used in its communication. As a second objective, it aims at proposing an alternative to these wordings. The latter would combine six shade types, defined by Individual Type Angle (ITA) values, a coloured reference chart and associated colour adjectives, highly corresponding to the six Phototypes previously defined by Fitzpatrick. Such alternative would overcome most references to both ethnic- and ethical-related issues.

## Résumé

Une revue des différents aspects de la couleur de la peau humaine est proposée. Elle montre que les remarquables travaux récents caractérisant la couleur de la peau humaine et sa variabilité se trouvent paradoxalement associés à des terminologies totalement inappropriées ou obsolètes. Cette revue vise aussi à proposer une alternative pour décrire la couleur de la peau, combinant six types de teintes, définies par les valeurs de l'Individual Type Angle (ITA), une carte référentielle des couleurs et leurs adjectifs associés. En étroite correspondance avec les six Phototypes préalablement définis par Fitzpatrick, une telle alternative permettrait de s'affranchir de la plupart des questions liées tant aux aspects ethniques qu'éthiques.

## Introduction

The natural colour of the human skin is a fascinating topic with regard to its universal, transversal aspect. It is a scientific domain merging biologists, ethno-geneticists, dermatologists, physicists, cosmeticians, historians and painters. For the latter, reproducing the skin colour (often referred as flesh tone) is hardly explicable: 'As for me, it is a green reddish, grey yellow, white, black and many neutral tints...' (Vincent Van Gogh, letters to his brother Theo). This famous master probably best expressed the complexity in defining with our limited words, the true colour of a human skin of so subtle tones. Three primary colours and their secondary mixed resultants constitute our basic palette reference and its infinite possible nuances: How subtle variations in blue or green could possibly be adequately, rationally, defined by verbal attributes?

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To summarize, the colour of the human skin has been, since 50 years, a field to which scientific expertise and technical skills brought a precise, neutral, objective 'vision'.

On a first hand, the present review aims at illustrating how, paradoxically, a well-conducted and fascinating science remains confronted to irrelevant, misleading, non-neutral wordings that may fuel too frequent social, ethical or ethnical conflicts. On a second hand, it aims at suggesting a possible alternative to these inappropriate wordings, according to recent findings.

## The basics: a captivating field of research, an old past of present features

The colour of the human skin is a criterion, among others, that is intimately linked to the evolution of mankind since approx. 200 000 years, emerging from our far primitive ancestors such as the famous 'Lucy', in eastern Africa [1]. The migrations of their descendants towards northern regions (Middle East, Europe, Asia and later, North America), 60 000–30 000 years ago [2–4], necessarily brought strict and selective adaptations to new climatic conditions. Among these, UV irradiance was likely a paramount factor. The now available spectrometer-equipped satellites (NASA) allowed the topographical array of UV radiance at the earth's surface to be depicted, the highest values being found at equator  $\pm 20^\circ$  (central Africa, central America, Indonesia), declining at higher latitudes. This largely explains that the human skin colour strongly (over 87%) correlates with UV radiance, as superbly reviewed by N. G Jablonski [5–7]. With regard to such migrations, the effects of UVs upon the human skin (vitamin D synthesis, melanisation, malignancies, etc.) are viewed as selective drivers of its evolution [8–10]. The protective function of the eumelanin black pigment makes dark skins much more protected – although not totally [11–13] – from malignant processes and their serious consequences, inversely to fairer skins. As previously mentioned, the cutaneous effects of UVs would have induced some metabolic changes through, at least, two biochemical pathways: vitamin D synthesis and folate photolysis. Dark skins therefore lower the UV-induced synthesis of vitamin D (body development) whereas maintaining folate status (DNA synthesis). Inversely, paler skins would favour vitamin D synthesis together with an increased degradation of folate, a hypothesis not accepted by all researchers [14]. The tremendous advances in genetic techniques not only ruled out the medieval notion of 'human races', but further outlined the important role of the MC1R gene (a melanocortin receptor) and more recently the SLC24A5 gene, in controlling the skin colour [15, 16]

of humans and animal coats. Their mutations associated (or not) with such large periods of time would have therefore favoured the process of a skin lightening. The question about whether such mutations arose before or after migrations from Africa received a recent and interesting new light [17]. Using allele frequency estimates (genes TYR, HERC2, SLC45A2) in European DNA samples of Eneolithic and Bronze ages (6500–4000 years ago), these authors demonstrate that a strong selection towards lighter skin, eyes and hair occurred some 5000 years ago, that is post-migrations. This finding suggests in addition that the colour of skin, eyes and hair is continuously evolving.

In brief, despite a vast domain of incertitudes, the evolution of the human skin colour appears to be associated with various and complementary Darwinian factors, being genetic, geographical and climatic which later influenced cultural and living habits such as hunting, harvesting and cultivating. This gross picture embraces our longest common past, our oldest origins, up to the present knowledge.

### Colour as a quantifiable parameter, figures only...

The colour of the human skin results from a complex (and individually specific) combination of various biochemical and physical factors such as melanin(s) and carotenoid(s) pigments, size of melanosomes, underlying reddish blood vessels and skin thickness [18, 19]. Qualitatively and quantitatively admixed, all create different palettes of mixed colours of various intensities, keeping in mind that the notion of colour implies a source of light: no light-no colour is a ruthless dogma, popularly expressed by the appropriate sentence according which 'All cats are grey in the dark'.

The need to describe colour(s) under a scientific neutral basis has progressively offered an efficient alternative answer to ambiguous descriptive terms. It brought clear harmonization in colour definitions towards a huge variety of applications, being industrial, medical, cosmetic and technical such as photographic or printing procedures (e.g. Pantone™). This vast and complex field of research grounds on different reference scales such as Munsell, L\*, a\*, b\* and RGB that all present specific criteria adapted to specific needs. On a technical viewpoint, progresses in electronics made precious instruments available, based upon absorption, refraction, reflection and diffusion of visible light when spotting a coloured surface. These vary from the simplest, hand-portable, to the most sophisticated devices. When adequately calibrated, they provide precise and reproducible results. They rapidly became rigorous 'blind' observers, free from human influence. As a result, they conferred colour a neutral parameter deprived from any other objective than describing the colour of industrial objects or that of animals, vegetables or minerals: a same green colour, measured by the L\* a\* b\* system, may indifferently apply to a frog, a leaf or an emerald. A complete review of such technical aspects can be found in specialized textbooks [20, 21].

Most experimental works dealing with skin colour give privilege to the L\* a\* b\* system where L\* refers to luminance, on a 0–100 scale (0 = black, 100 = white), a\* and b\*, red–green and yellow–blue vectors (of same range –128 to +128), respectively, according to the CIE (Commission Internationale de l'Eclairage) recommendations, established in 1976. Practically speaking, a small illuminating probe (approx. 2 cm<sup>2</sup>) is gently pressed onto the skin surface and records these three parameters within seconds. Subsequent mathematical transformations of L\*, a\*, b\* yield additional parameters such as chroma ( $\sqrt{a^{*2} + b^{*2}}$ ) and hue ( $\arctan b^*/a^*$ ) of a

given colour. Chroma basically reflects its saturation level (distance to the nearest grey point), whereas hue is often used as a reference for shades, that is their positioning within a\* and b\* coordinates.

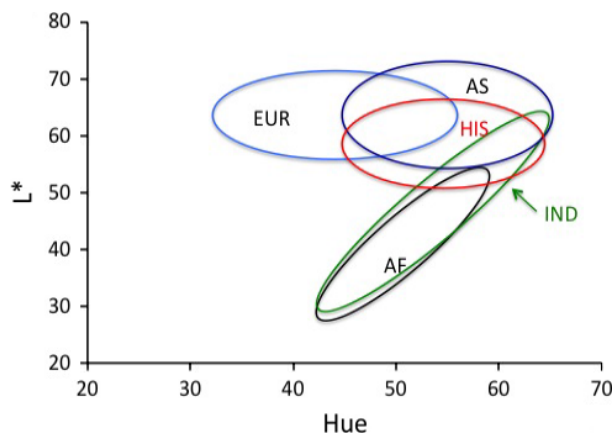
Thanks to the pioneering work of Chardon [18], another parameter extracted from a trigonometric function, the Individual Typology Angle (ITA° =  $[\arctan ((L^* - 50)/b^*) * 180/\pi]$ ), is now gaining a growing interest. It is a continuous criterion that 'quantifies' the natural skin colours and their possible changes (tanning, whitening, etc.) [18, 22–24]. Varying from 10° (dark brown tones) to 55° and above (pale tones), ITA covers all possible tones of the human skin, worldwide. As recommended by guidelines from the US FDA or Cosmetics Europe (formerly Colipa) [25], ITA affords four boundaries between figures and wordings: 10–28°: Tan/Matt; 28–41°: Intermediate; 41–55°: Light; and >55°: Very Light. Such proposal, although useful, has limitations since probably too restrictive or imprecise.

The colour of the human skin was indirectly and brilliantly approached by Pr Fitzpatrick [26], who defined skin Phototypes (I–VI) on a functional basis, according to their different responses *vis à vis* sun exposure (never tan-always burn, tan a bit-burn a bit, etc.). It remains nevertheless clear that, from I to VI, skin Phototypes grossly reflect the palette of colours of the human skin, from pale to dark tones, respectively. Due to their discontinuous features and possible divergences between self-assessments or observers, it is likely that ITA will progressively replace such classification, at least for research purposes. As examples, ITA correlates well with UV-induced DNA damage [27, 28] or skin response to UV exposure [29], best describes the Photo-ageing process or the effect of treatments [30–32] and is a precious marker in typological studies [22, 24].

### Skin colour: a reliable phenotype?

ITA, as other L\* a\* b\* parameters, confers a figure to skin colour, assumed to being a member of the human phenome, the assembly of all possible phenotypes. Inversely to many molecular phenotypic markers (HLA, HPA, ABO groups, Rhesus, etc.) of discontinuous (i.e. absent/present) and invariant character, the human skin colour not only shows a continuum of shades but expresses slight individual changes along the lifespan [24, 33, 34] with age, sun exposures and occupations. The latter account for site variations in skin colour within a same individual, that is exposed skin sites (face, dorsal forearms) vs. less or not exposed (ventral forearm, buttocks). Viewing the human skin colour as a strictly defined or fixed phenotype is therefore questionable. Same comments could apply to human hair in its natural colour – highly variable among Europeans – and shape, from straight to kinky as a straight shape is by no way a specific Asian/Indian trait [35].

Recent works [36, 37] from L'Oréal laboratories successively analysed, through the same radio-spectrometric equipment (Chromasphere®), and mapped the colours of the facial skin of 4228 women from five ethnic groups (European, Asian, Hispanic/Latino American, African/African American, Indian). A simplified illustration (Fig. 1), extracted from these works, allows two very large subgroups to being grossly distinguished according to variances in L\* and hue values, given here as approximate figures. One gathers European, Hispanic/Latino and Asian women, of a rather limited range in L\* (52–75) and a larger range in hue (30–65). The other includes the group of darker-skinned people (Indian and African/African American) of almost inverse variations, higher L\* range (28–65), lower hue range (42–65). A very recent work from the same group (in press), using same equipment and protocol [38],



**Figure 1** Simplified gross mapping of the shades of human skin, through  $L^*$  and Hue factors, recorded by spectro-photometric measurements on the faces of 4228 women from five ethnic groups. EUR, European/Caucasian women ( $N = 1339$ ); AS, Asian women ( $N = 2111$ ); HIS, Latino American women ( $N = 314$ ); AF, African and African American women ( $N = 304$ ); IND, Indian women ( $N = 160$ ). Data extracted from Refs [35, 36], given as approximate values.

focusing on the facial skin colour of 1195 Indian women from various Indian cities, confirmed such mapping. Figure 1 allows two major aspects to be reported. On a first hand, such a large variation in  $L^*$  confirms observations from ethnologists that 'dark skins' comprise a large palette of tones (darker, lighter). On a second hand, the large overlapping shades of Indian and African skin indicate that a brown or dark brown skin is not a specific African trait. Such overlaps, also observed between the skin colour of Asian and European or Latino American, make clear that standard photographs limited to their forearms or cheeks will not allow to confer a given ethnic origin with certainty. In real life, a spontaneous attribution of an ethnic origin to a given person is mostly performed at a glance, by observing additional and more significant facial phenotypes such as shape and colour of eyes, and hair shape. Skin colour, in such a process, appears secondary.

Interestingly, the view of the general shape of Fig. 1 – its '7 like' aspect – spontaneously induces a striking resemblance to the earth geography, latitudes and past roads of migrations, where the large group of African and Indian people mostly reside within a  $0 \pm 20^\circ$  latitude range and the other group being located in northerner regions, reflecting the dependence of skin colour with UV radiance, as previously mentioned.

In brief, skin colour, as compared to many other biological criteria and despite its important but variable sun-protective function, can be viewed as a back-staged phenotype. It nevertheless unfortunately carries strong cultural and social consequences, often distorted by an approximate and/or unsuitable communication. Illustrations of such wordings, often used in different media (publications, speeches, etc.), are given below.

### Poor, biased and irrelevant associated wordings

#### Black, White

From a physicist viewpoint, these attributes cannot be assimilated to a colour, the first being a complete extinction or total absorption

of light (cf black holes), the second emitting a complete visible spectrum (total reflection): 'No black ornaments for the burial of Monet, black is not a colour!' (G. Clemenceau, *The Tiger*, close friend of the famous French painter Claude Monet). As for skin, these terms are over-simplifying: the darkest and fairest skins, as measured through colorimeters or spectro-radiometers, show  $L^*$  values ranging approx. 30–75, respectively, a 45 global span within the 0–100 range of  $L^*$ , making 'black' or 'white' adjectives of irrelevant meaning as far as skin is concerned. Although possibly used as easy shortcuts in common conversations, these adjectives are scientifically inappropriate: skins black as carbon black or white as a paper sheet are unknown human phenotypes.

On such aspect, human hair differs. It offers a wider palette of shades, ranging from black to extreme blond, up to red or 'white hair', seen white since transparent, deprived of basal hair melanocytes and melanin pigments [39, 40]. Such palette is since long standardized on a 1–10 scale (1 = black, 10 = extreme blond) by professionals dealing with hair dying. Same holds true with regard to animal furs that range from black to white: horse breeders or geneticists use 10–40 attributes to describe the various coats of horses such as Bay, Gray, Champagne, Buckskin, Isabelle, Chestnut and Dun. [41, 42].

### A skin colour of strong cultural and social impacts

Since long, many popular cultures or folklores conveyed to 'black' and 'white' strong social and moral references. Many idioms associate 'black' with mysterious, tenebrous or illegal situations (black intrigue, blackmail, black market, etc.) up to the intriguing 'black holes' of astrophysicists. In contrast, they associate 'white' to 'light', 'purity', 'truth', as cultural or religious codes (e.g. the white robe of the bride). Such binary perception likely arose from night/day shifts, inducing contrasted emotions, that is fear/night vs. safety/day felt by our far ancestors. This duality probably contributed, to some extent, to the emergence of an intolerable 'racist theory' stating that some 'human races' were superior to others, an unbearable notion that, under a dreadful logic, brought the worse human consequences such as slavery, apartheid and genocides.

In many countries or continents such as Asia or Africa, the desire of a fairer skin is commonly and strongly expressed for social or aesthetic reasons. In Asia, a dark skin is associated with outdoor hard workers. Inversely, a pale facial shade is associated with high social class activities, that is 'princesses in a castle' protected from sun. This explains, in a large part, the high demand and commercial successes of safe 'whitening' cosmetic products in these countries, although the term 'lightening' seems more appropriate for the reasons exposed above. In Africa, or among African American people, such desire of a colour lightening is more driven by the frequent symptoms of a heterogeneous facial pigmentation (e.g. dyschromia) [36]. Driven to the extreme, as too frequently observed in Africa [43–45], this strong quest leads to serious health problems when potent drugs are regularly topically applied (corticoids, hydroquinone, retinoids, etc.) or toxic elements such as mercury, most being illegally purchased, or fake products of unknown compositions.

Cultures or fashions are powerful drivers of opposite attitudes towards sun exposure and tanning. In Europe, although a fair skin was initially seen as a mark of a 'high-class society' (end of 19th and early 20th century, cf Mrs Chanel), such perception drastically changed. From the 1930s, the Western culture turned to associate a tanned skin with a healthy condition, induced by the growing practice of outdoor sports (surf, tennis, sailing, golf, etc.).

In contrast, people living in hot, sunny regions (Africa, Middle East) traditionally protect their skin through heavy clothes (veiled). Hence, opposite cultural behaviours bring a true paradox: less sun-protected humans (Phototypes I–III) became sun-seekers, leading to serious consequences (e.g. melanoma among Australians of European ancestry). In contrast, less sun-sensitive people (Phototypes IV–VI) remained sun-hiders. In the latter case, such strong external protection leads to a low or deficient status in vitamin D in many people [46–48].

### Skin of colour

Such definition sounds a pleonasm as all healthy human skins are naturally and differently coloured. In addition, it suggests a rather unfair reference issued from an authoritative Western statement, evoking some 'skins differently coloured than ours'. All apples, despite a wide range in phenotypes/colours, belong to the same ancestral species (*Malus sieversii*), comprising numerous cross-breeds of more than 11 000 varieties. Would 'apple of colour' be a meaningful assertion?

Based upon the spectro-radiometric measurements mentioned above, researchers from L'Oréal laboratories illustrated the continuum of the human skin colour under a standardized colour chart, available online [49], creating 66 shades. It is based upon 11 levels of lightness (boxes 1–11) and six colour levels (boxes A–F), ranging from A1 (pale pinkish) to F11 (darkest brown). From demographic or ethnologic viewpoints, such chart suggests that skin colours from A4 to F11 likely cover 80–90% of the world human population, whereas skin colours from A1 to F3 grossly represent the so-called Caucasian type. The same holds true for hair colour where black or brown shades (tones 1–3) are shared by more than 90% of the total population [50]. In brief, the eumelanin/black pigment clearly predominates within the skin and hair of *Homo sapiens*, whereas pheomelanin/red–yellow pigment may be viewed as a mutation-induced pigment, as previously mentioned. A comparable situation is found with eye colouring where eu-melanised eyes of dark tones (black to brown) largely predominate, worldwide.

'Ethnic skin' seems another version of the previous pleonasm, all skins (and their owners) being ethnic by definition since inheriting genomes from ancestries, past migrations, interbreedings, etc. Brazil is probably the best example of such ethnical cross-breeds that led to a mosaic of phenotypes from multi-ethnic populations. The Brazilian demography (about 200 millions of inhabitants) shows that, using official Brazilian terms ([www.brasilbeleza.com](http://www.brasilbeleza.com)), 55.2% of people belong to 'Branços' (originating from 'white' Europeans) category, 39.3% to 'Pardos' (metis from past multi-cross-breeds between Indians, Africans, Europeans, etc.), 4.9% to 'Negros' (African origin alone) and 0.5% to 'Ameleros' (from Asian origin, Japan mostly). Hence, Brazil unsurprisingly shows the largest variations in skin shades and hair shapes [35, 51].

### Non White

This expression, sometimes used, is most surprising. Every colour being non-white by definition, this apparently 'politically correct' term is a scientific non-sense, similar to 'Non green' or 'Non blue'. Billions of African, Chinese, Japanese, Indian and Mexican people share such 'Non White' attribute. It therefore clearly brings a useless confusion since unable to differentiate the respective biological characteristics of these so large populations. 'Non White' likely originates from American authors, as an attempt to replace 'Non Caucasian'. The last 2010 U.S. census [52] opted for the term

'White' instead of 'Caucasian', although the latter term remains quoted by some U.S. officials such as Mrs H. Clinton [53]. A full respect of both mankind and scientific rationale implies to desert the term 'Non White'.

### Caucasian ('Caucasoid')

This term, created in 1785, seems outdated. It refers to Caucasus Mountains, as the geographical region (Georgia, Armenia) claimed to geologically separate Europe (North/West) from Asia (South/East). 'Caucasians' therefore became distinguished from their Asian counterparts referred as 'Mongoloids', a term used in the 18 and 19th centuries, now abandoned. Nowadays, 'Caucasian' still remains intensively used. It is not only imprecise but gathers a large palette of various phenotypes (Celts, Mediterraneans, etc.) in hair colours/shapes and skin Phototypes (I–IV). As Caucasus is a very limited geographical region, the very term 'Caucasian' should be rationally replaced by 'Continental European', in line with the modifications brought by the National Library of Medicine in 2003 [54]. The latter now includes the terms 'Whites' and 'Caucasians' under the same heading 'European Continental Ancestry Group'.

### Human races

It is probably the most irrelevant and unacceptable expression. Paradoxically, although being a biological non-sense, these associated terms still exist in some legislations, the United States in particular. The very word 'race' (or 'racial') remains included within US official documents dealing with identity data and/or the successive census of US residents. The latter, edited by the US Census Bureau, received many modifications from the very beginning of U.S. history (1790) to the present time, as regards references to 'race' and skin colour, the term 'ethnic' being a recently suggested alternative. The recommendations (1997), issued by the A.A.A. (American Anthropological Association) to combine 'race' and 'ethnicity', were not adopted in the 2000 and 2010 US census. Quotes of A.A.A. recommendations illustrate well the imbroglia of the present situation: 'Yet the concept of race has become thoroughly-and perniciously-woven in the cultural and political fabric of the United States. It has become an essential element of both individual identity and government policy. Because so much harm has been based on "racial" distinctions over the years, correctives of such harm must also acknowledge the impact of "racial" consciousness among the US populace, regardless of the fact that "race" has no scientific justification in human biology...' [55].

In fact, the official U.S. 'classification' of a given individual includes reference to his/her two ascending generations. If only one of his/her four grandparents was categorized as 'Black', this person will be categorized as 'Black'. In brief, as in many other cases, scientific facts are not actively integrated, not to say ignored, in the edification of now outdated legal labyrinths.

The question of past origins remains nonetheless a highly complex issue to which analysis of DNA/genome is of little help, taking into account its high polymorphism even in close geographical regions where people of same skin shades reside [56, 57]. Nowadays, ethno-geneticists much favour language as additional and important criterion, although not perfect, to assess the origin of a given individual: speaking the same language than his/her four grandparents makes this person a likely descendant of the same ethnic group. As a matter of fact, the very words 'Hispanic Ancestry' more cover a language criterion (Spanish as mother tongue) than objective or clear-cut phenotypes. Skin colour appears, there again, a backstage criterion.



**Table I** Suggestion of a possible association of six large human skin shades through both objective data and possible wordings, corresponding to the six Fitzpatrick's Phototypes (I–VI)

Shade type	ITA range*	English terms†	Correspondences with* L'Oréal Chart
I	>55	Pale	A1-C2
II	42–55	Fair	D2-F3
III	35–41	Golden	A4-B5
IV	29–34	Tan	C5-F6
V	21–28	Brown	A7-F9
VI	10–20	Dark brown	A10-F11

\*Data to be confirmed or refined through colour measurements on large panels of different ethnics.

†Proposed verbal descriptions of shades/colours. Tan, defined as brown–yellow, may express a more brownish (darker) shade than Golden, of a more yellowish tint.

### Which classification?

Communicating about skin colour is nothing but an easy task, aiming at an acceptable balance between neutral data and their translations by decent wordings. Dictionaries that define all colours [58, 59] afford hundreds of possible terms. Hence, attributing to some perfect concordance with the skin colour palette is vane. The guidelines edited by Europe Cosmetics, previously mentioned, constitute a valuable progress in associating ITA ranges and wordings. However, taking into account the vast continuum of skin shades, separating the latter into four wordings (Tan/Matt, Intermediary, Light, Very Light) is probably a too narrow classification, where the very word 'intermediary' appears quite fuzzy. Extending these four classes to an increased but reasonable number of boundaries, of clearer wordings, seems a rationale objective, as proposed below.

### Proposal

As Phototypes indirectly depict six domains of colours/shades, a rational approach would adopt the same colour typing range, leading

to six shade types in line with the six functional categories of Pr Fitzpatrick (Phototypes I–VI). Table I illustrates how shade types could be associated with ITA range and the mentioned L'Oréal colour chart. Such a table is only given as a conceivable indicator as the proposed boundaries of ITA and their agreement with the L'Oréal colour chart call for experimental confirmations on large cohorts of subjects. In short, such proposal associates functional and physical criteria, knowing that some discrepancies may well co-exist: when tanned (post-sun exposure), a shade II may shift to shade III although remaining, biologically, a Phototype II. This proposal, which combines the six shades with six Phototypes, and slightly different from the Colipa guideline in 2007 [24], was previously suggested by the European Commission in 2006 [60]. The latter, however, indicates unrealistic boundaries (negative values of ITA) corresponding to an unreal 'black' denomination or a still fuzzy 'intermediary' tone. The reasons why such recommendations were not followed (modified or improved) are unknown.

### Conclusion

The present review aimed at illustrating some paradoxical aspects between neutral, scientific facts and their difficult or awkward verbal translations. A critical analysis of data related to human skin colour, along the planet, confers the latter a minor human phenotype. Unlike animal skins and coats that obey to strict Darwinian *imperata* (camouflage/survival/protection), the colour of the human skin does not convey any particular biological advantage other than sun-related mechanisms of cutaneous damages or benefits. Homo sapiens can hardly be restricted to a mere biological machinery packaged in an envelope of various colours. Communicating about the colour of the human skin may often be a source of strong individual, social and ethic impacts. On this paramount account, it clearly deserves comparable and proper improvements than those brought by so many fruitful scientific advances.

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